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Implantable Cardioverter Defibrillator

based on clinical cases from

Medtronic ICDs

TABLE OF CONTENTS

Chapter 4 : Discrimination   167

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Foreword

The Stimuprat team is delighted to offer you this book on the specifics of interrogation and programming of Medtronic implantable cardioverter defibrillators (ICDs). Much more than the actual functioning of the devices, which has changed little, recent years have seen significant developments in programming, with a particular focus on strategies to minimize the number of inappropriate or unnecessary therapies. For this reason, we have updated the previous version of this book with plots from the most recent platforms.

The book is divided into several chapters (counters, therapies, oversensing, discrimination), each with demonstrative clinical cases covering the basic rules of defibrillator programming, as well as the specific operating and programming features of Medtronic devices. Optimal programming requires in-depth knowledge of the algorithms used by the various manufacturers. This book was written in collaboration with Medtronic's French technical team, Delphine, Thomas, Denany, Adriana and, in particular, Leslie, the latest addition to the team, who brought her competence, dynamism and freshness to the project.

Enjour your reading!

Counters

1 analysis of a VF trace recorded by the device

Patient

Male implanted with a triple-chamber defibrillator (Cobalt CRT-D) for ischaemic cardiomy-opathy; hospitalisation for loss of consciousness with a shock from the device.

Medtronic

Treated VT/VF Episode #10

Device: Cobalt™ XT HF Quad CRT-D
DTPA2QQ

Serial Number:

Date of Interrogation: 05-May-2022 21:48:22

Patient: ID: Physician:

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	0	**40J**	Yes	10	05-May-2022	17:54	:17	102/333	---/333	Active

• V-V Paced   ○ V-V Sensed   ■ A-A Paced   □ A-A Sensed

FVT = 250 ms   VF = 320 ms

Detection   39.1 J   Term.
↓ _____ 11 s _____ ↓ ____ 6 s ____ ↓

1 What diagnosis was made by the defibrillator for this episode?

On the first page, we find a range of information relevant to the diagnosis made by the device: the type of episode (in this case, an episode classified as VF), the therapies (a 40 J shock is described as effective), the date and time of the episode, its duration and the mean atrial and ventricular rates.

2   How many detection zones are programmed?

The VF zone is divided into 2 zones: the FVT zone from 320 to 250ms and the VF zone from 250ms; the lower limit of the VF zone is set at 320 ms, which reflects the fact that the VF counter applies from 320 ms (same probabilistic counter implemented for FVT and VF zones); the horizontal lines observed on the plot correspond to the limits of the programmed detection zones.

3   At the start of the episode, are the atrial and ventricular complexes paced or sensed?

The plot allows analysis of the atrial and ventricular intervals over the entire episode; on the new defibrillator platforms from this manufacturer, additional information is available with differentiation between sensed and paced atrial or ventricular events; in this example, the atria are sensed (white squares) and the ventricles are paced at the start of the episode (black circles), which is expected for a CRT defibrillator.

4   What diagnosis is suggested by the interval plot?

The plot shows a sudden acceleration of the ventricular complexes with atrioventricular dissociation (ventricular rate > atrial rate) suggestive of a very rapid ventricular arrhythmia detected in the VF zone.

5   What therapy is delivered?

A maximum output shock is delivered after an episode lasting around 16 seconds (5 seconds for initial diagnosis, then 11 seconds for capacitor charging and confirmation at the end of charging); the shock appears to be effective.

6 What do EGM1 and EGM3 correspond to?

This plot shows EGM1 corresponding to bipolar atrial sensing (Atip to Aring) on the first line, EGM3 corresponding to bipolar ventricular sensing on the second line (RVtip to RVring) and markers and intervals on the third line
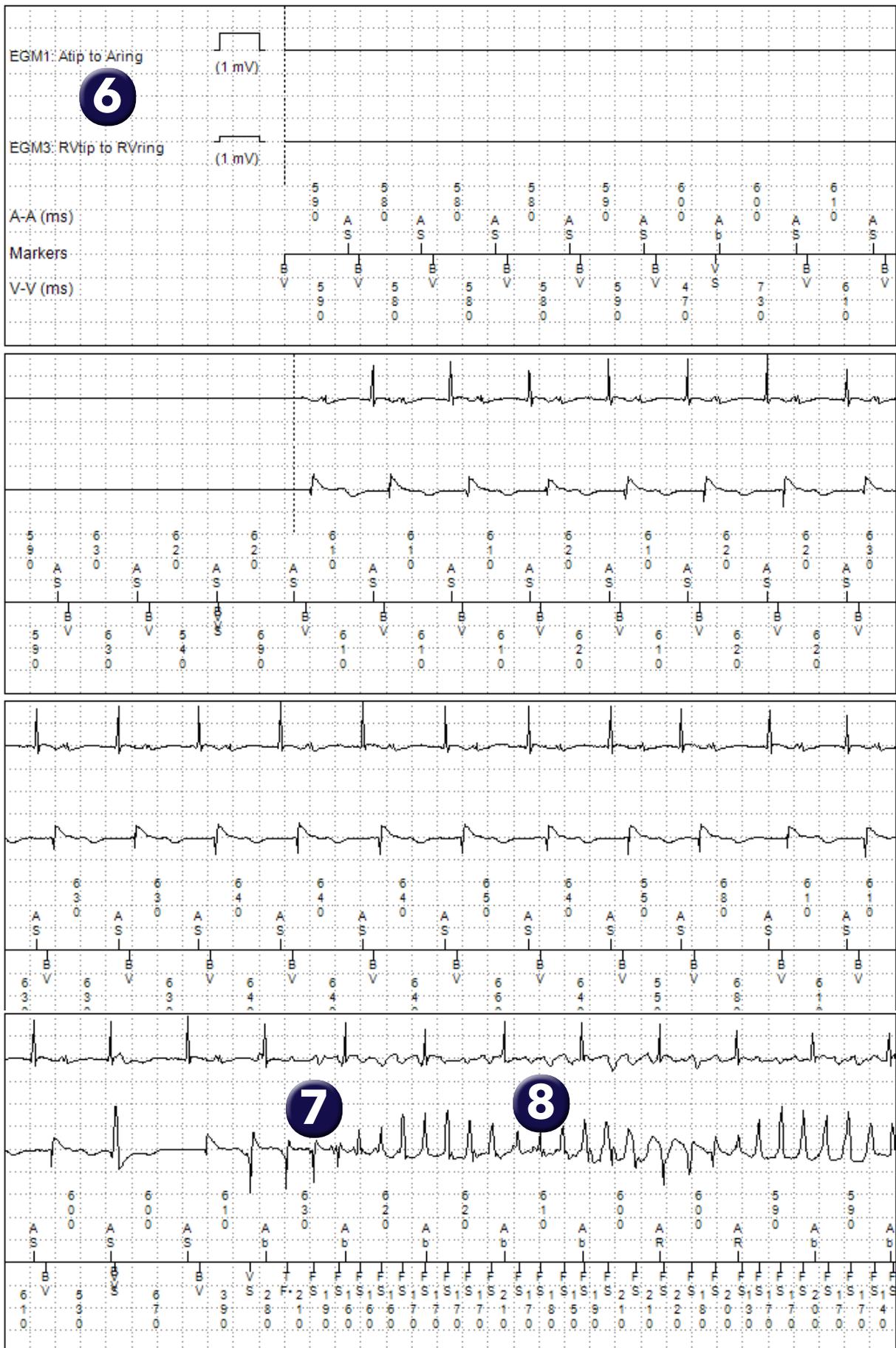
7 What do the different markers mean?

The first TF. marker corresponds to a cycle detected in the FVT zone, the FS markers to cycles detected in the VF zone.

8 What type of arrhythmia is it?

This is ventricular fibrillation: ventricular arrhythmia (ventricular rate > atrial rate), very rapid (> 300 beats/minute), polymorphic and irregular.

9 What does the FD marker stand for?

The FD marker indicates that the initial VF counter programmed at 30/40 has been filled; 30 cycles classified as TF or FS can be counted; cycles detected in the FVT zone and the VF zone implement the same FV counter.

10 Why are ventricular cycles labelled VS?

Capacitor charging begins following the FD marker; in fact, a maximum output shock is the first therapy programmed for this type of arrhythmia; during capacitor charging, unlike during initial detection, all cycles are systematically labelled VS regardless of their rate (slow or fast cycles).

11 Explain the markers at the end of capacitor charging

The CE marker corresponds to the end of capacitor charging; this marks the start of the confirmation phase for arrhythmia persistence; during this confirmation phase, all cycles (slow or fast) are labelled VS; after 2 fast ventricular cycles, a shock is delivered (CD), synchronised to a sensed ventricular complex.

12 What happens once the shock has been delivered?

After the shock has been delivered, a blanking period of 520 ms begins, to avoid oversensing the polarisation induced by the shock; there is also a period of 1200 ms

following the shock, when no ventricular pacing is possible; the shock was effective, with the return of sinus rhythm.

Medtronic   **Treated VT/VF Episode #10**

Device: Cobalt™ XT HF Quad CRT-D DTPA2QQ   Serial Number: Date of Interrogation: 05-May-2022 21:48:22

Patient: ID: Physician:

Episode #10: 05-May-2022 17:54:33

Episode Summary

Initial Type	VF (spontaneous)
Duration	17 s
A/V Max Rate	Unknown/333 bpm
V. Median	333 bpm (180 ms)
Activity at onset	Active, Sensor = 81 bpm
Last Therapy	VF Rx1: Defib, Successful

Initial VT/VF Detection Withheld By

None

Therapies	Delivered	Charge	Ohms	Energy
VF Rx1 Defib	39.1 J	10.63 s	59 ohms	0.0-40 J
|				
Termination				

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	320 ms (188 bpm)
FVT	via VF			250 ms (240 bpm)
VT	Off	48	12	
Monitor	Monitor	40		360 ms (167 bpm)

13

PR Logic/Wavelet

AF/Afl	On
Sinus Tach	On
Other 1:1 SVTs	On
Wavelet	On, Match = 70 %
Template	None, Auto = On
SVT V. Limit	240 ms

Other Enhancements

Stability	Off
Onset	Off
High Rate Timeout	
VF Zone Only	Off
TWave	On
RV Lead Noise	On

Polarity   **RV**

Pace Polarity	Bipolar
Sense Polarity	Bipolar

---

13 What is the main information on this episode summary sheet?

This summary sheet details certain elements specific to the episode (identical to those found on the interval plot), the charge time and the impedance of the shock delivered (an essential parameter for evaluating device operation which should be systematically checked when a shock has been delivered) as well as the main programming parameters.

Key messages

- For each trace recorded by the system, an interval plot, the EGM and a summary are available, each providing information that is essential for a proper understanding of the event.

- Starting the analysis with the interval plot gives an overview of the episode (duration, therapies delivered, etc.) and the programmed parameters (number of zones and rates); sometimes the characteristic appearance of the plot is sufficient to strongly suggest a diagnosis (cloud of points for lead dysfunction, rail-like appearance for oversensing of the T wave, etc.).

- The analysis of the tracing is the essential part of the analysis, the choice of the 2 EGM tracks displayed is configurable; for a double or triple chamber defibrillator, it is usual to programme the recording of the atrial bipolar channel and the ventricular bipolar channel to better understand the operation of the device and to facilitate differentiation between ventricular arrhythmias and supraventricular arrhythmias; for a single-chamber defibrillator, recording the shock channel between the can and the right ventricular coil in addition to the bipolar channel may make it easier to interpret the tracing, as the shock channel provides information similar to that of an ECG lead.

- The summary sheet details the main parameters programmed (number of zones, zone limits, counters, discrimination, detection polarities and sensitivity values), which are essential for understanding device function during the episode; each time a shock is delivered, it is essential to check the impedance of the shock, which provides crucial information about how well the device is working.

2 a ventricular arrhythmia in the VF zone

Patient

Patient with hypertrophic cardiomyopathy implanted with a single-chamber defibrillator (Visia AF VR) hospitalised for loss of consciousness.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VF	1		Yes	81	15-Oct-2020	12:43	:10	222	222	Active
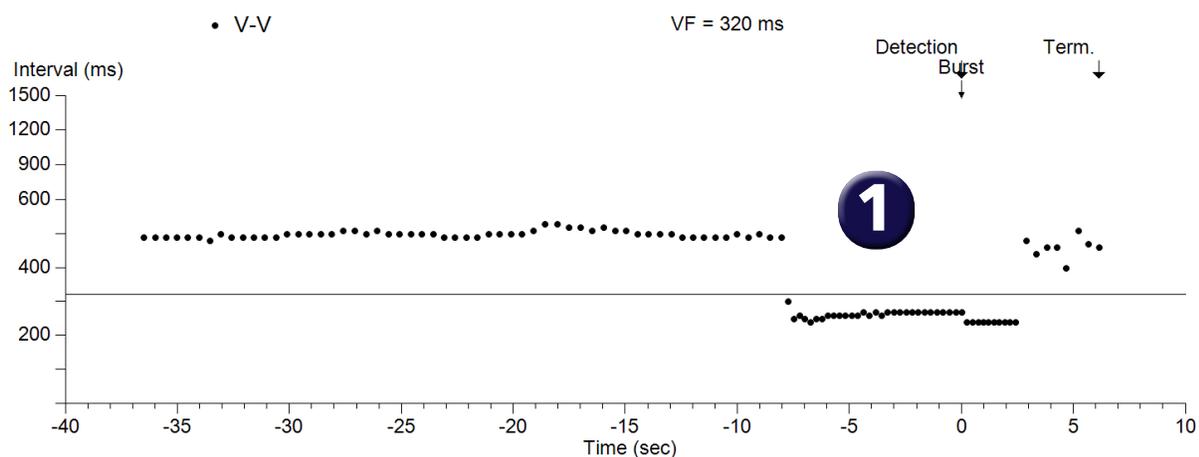
1 What diagnosis is suggested by the interval plot?

The episode was classified as VF by the device; a single detection zone was programmed (VF zone from 320 ms); the plot shows a sudden acceleration with regular ventricular cycles detected in the VF zone; a burst is delivered resulting in a slowing of the rate.

2 What do EGM1 and EGM2 stand for?

On this plot, we find EGM1 on the first line corresponding to bipolar ventricular sensing (RVtip to RVring), EGM2 on the second line corresponding to the shock channel (Can to Coil) and a third line with markers and intervals.

EGM1: RVtip to RVring (1 mV)

2

EGM2: Can to RVcoil (2 mV)

Markers
V-V Interval (ms):

| VS | 490 | VS | 490 | VS | 490 | VS | 490 | VS | 490 | VS | 500 | VS | 490 | VS | 500 | VS | 490 | VS | 490 |

3

| VS 300 | FS 250 | FS 260 | FS 250 | FS 240 | FS 250 | FS 250 | FS 260 | FS 260 | FS 260 | FS 260 | FS 260 | FS 260 | FS 270 | FS 260 | FS 270 | FS 260 | FS 270 | FS 270 | FS 270 | FS 270 | FS 270 | FS 270 | FS 270 | FS 270 |

4   **5**

| FS 270 | FS 270 | FS 270 | FS 270 | D 240 | P 240 | P 240 | P 240 | P 240 | P 240 | P 240 | P 240 | P 240 | P 240 | P 240 | F 480 | 4 840 | VS 460 | VS 460 | VS 460 | VS 460 | VS 460 | VS 510 | VS 470 | VS 470 |

VF
VF Rx 1 Burst Before Charging

3 What type of arrhythmia is it?

This is a regular, monomorphic arrhythmia detected in the VF zone, probably corresponding to rapid VT.

4 How is the initial detection counter in the VF zone programmed?

The initial counter in the VF zone has been set to 30/40.

❺ What therapy is delivered?

A burst before charging was delivered; the burst was effective and terminated the arrhythmia (the morphology of the QRS complexes was different from the morphology during tachycardia, reinforcing the presumed diagnosis of VT).

Key messages

- In a double or triple chamber defibrillator, the comparison between atrial and ventricular activity sometimes provides certainty (ventricular rhythm faster than atrial rhythm) in terms of differentiating between ventricular arrhythmias and atrial arrhythmias; in a single-chamber defibrillator, certainty of the diagnosis is usually much more difficult; in this example, the diagnosis of VT is probable (different appearance of ventricular EGMs in tachycardia and post-termination, effectiveness of anti-tachycardia pacing, etc.) even if each criterion taken individually does not constitute definitive proof.

- By definition, ventricular fibrillation is a very rapid, irregular and polymorphic arrhythmia; it indicates the existence of chaotic ventricular activation, which becomes very disorganised; the diagnosis of VF made by a defibrillator is not an electrophysiological diagnosis (evidence of an irregular and polymorphic arrhythmia) but is based solely on an assessment of heart rate (faster than a programmable limit); in this example, this episode was classified as VF by the device even though it was clearly VT (regular and monomorphic arrhythmia) due to its rapidity.

- The observation that many patients record VT falling in the VF zone has led to a change in recommendations and programming of anti-tachycardia pacing as first-line treatment to reduce the number of shocks delivered.

③ utility of a probabilistic counter in the VF zone

Patient

Patient with hypertrophic cardiomyopathy implanted with a single-chamber defibrillator (Visia AF VR) hospitalised for loss of consciousness.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VF	0	35J	Yes	44	30-Mar-2022	22:22	:18	231	261	Rest
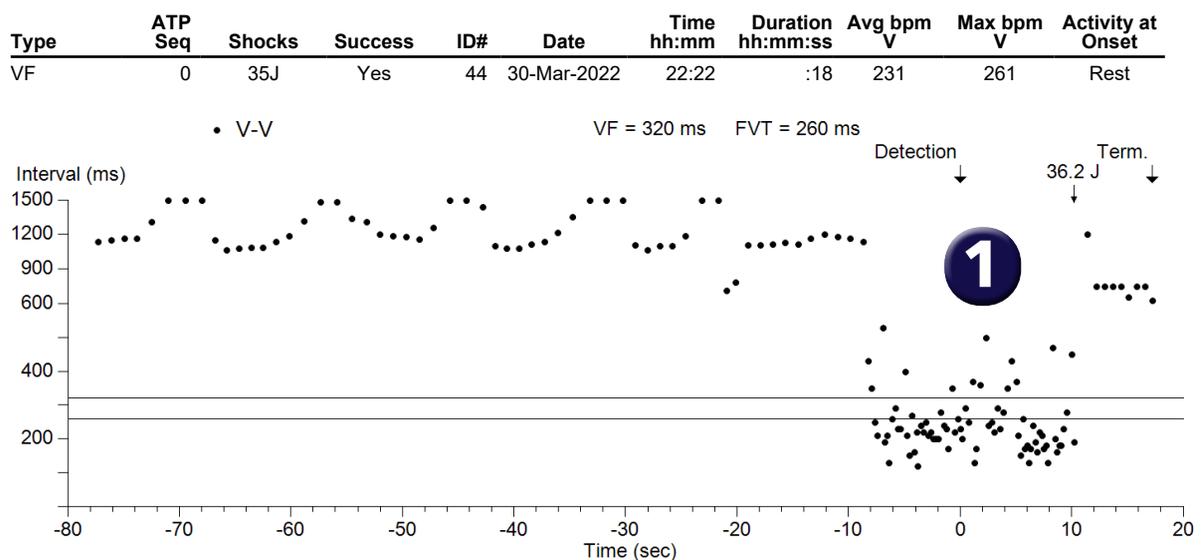
① What diagnosis is suggested by the interval plot?

The plot shows an episode classified as VF, the duration of the ventricular cycles during the tachycardia being very variable; some cycles are very fast (150 ms) and others slower (500 ms); the 2 diagnoses suggested by this plot are: 1. a VF-type ventricular arrhythmia with intermittent undersensing (explaining the slower cycles); 2. oversensing of non-physiological signals (lead dysfunction, etc.).

② What type of arrhythmia is it?

This is VF (very rapid, irregular, polymorphic arrhythmia); the shock channel (EGM2) allows the chaotic nature of the electrical activity to be clearly visualised.

3 How do you explain this VS marker during initial detection?

The cycle is classified as VS following ventricular undersensing of the previous complex.

4 How is the initial detection counter programmed in the VF zone?

The initial counter is set to 30/40; it is filled because 30 cycles are classified as either VF or FVT (FS and TF cycles fill the same VF counter, the FVT counter being set to via-VF) with only 3 cycles classified as VS (i.e. 30 rapid cycles out of 33); the cycles labelled FS and TF do not need to be consecutive; the existence of a few undersensed cycles does not prevent the counter from being filled and does not compromise patient safety.

5 How do you explain these VS markers?

Capacitor charging begins following the FD marker, a maximum output shock being the first therapy programmed for this type of arrhythmia; during capacitor charging, even if the ventricular cycles detected are very rapid and correspond to the VF zone, they are systematically labelled VS; in this example where sensing is imperfect, short and long cycles are all labelled VS during charging.

6 How do you explain device function at the end of charging?

At the end of charging, both fast and slow cycles are labelled VS; a shock is delivered if at least 2 out of 5 cycles are considered fast; here the first cycle following the CE marker is fast (280 ms), the second is slow (450 ms), the third is fast (190 ms) and so the shock is delivered (CD).

Key messages

- One of the special features of Medtronic™ devices is that the counting method differs completely between the VT zone (consecutive cycles) and the VF zone (probabilistic counter).

- This diagram explains how the VF counter works; it is a probabilistic counter (X/Y rapid cycles) which requires a minimum of 75% rapid cycles (possible settings: 9/12, 12/16, 18/24, 24/32, 30/40, etc.).

- Ventricular fibrillation is by definition a rapid, chaotic arrhythmia, with ventricular signals of low and/or variable amplitude; all these characteristics increase the risk of undersensing, with the occurrence of signal amplitudes below the programmed sensitivity (nominal value of 0.3 mV) and often with great beat-to-beat variation in amplitude, which can fool the sensing circuit of the defibrillator because it uses a sensitivity level that adapts in relation to the previous signal.

- The value of 75% fast cycles was chosen to achieve an optimum balance between correct sensing of ventricular fibrillation (tolerating a certain number of pseudo-long cycles as a result undersensing) and the need to avoid filling counters in the presence of T wave, P wave or R wave oversensing (frequently associated with 50 % short cycles).

- This plot shows intermittent undersensing during VF but no significant impact on detection of the episode, with the probabilistic counter tolerating a maximum of 25% long cycles related to undersensing.

4 spontaneous termination of a ventricular arrhythmia

Patient

Patient with ischaemic cardiomyopathy implanted with a triple chamber defibrillator (Claria CRT-D).
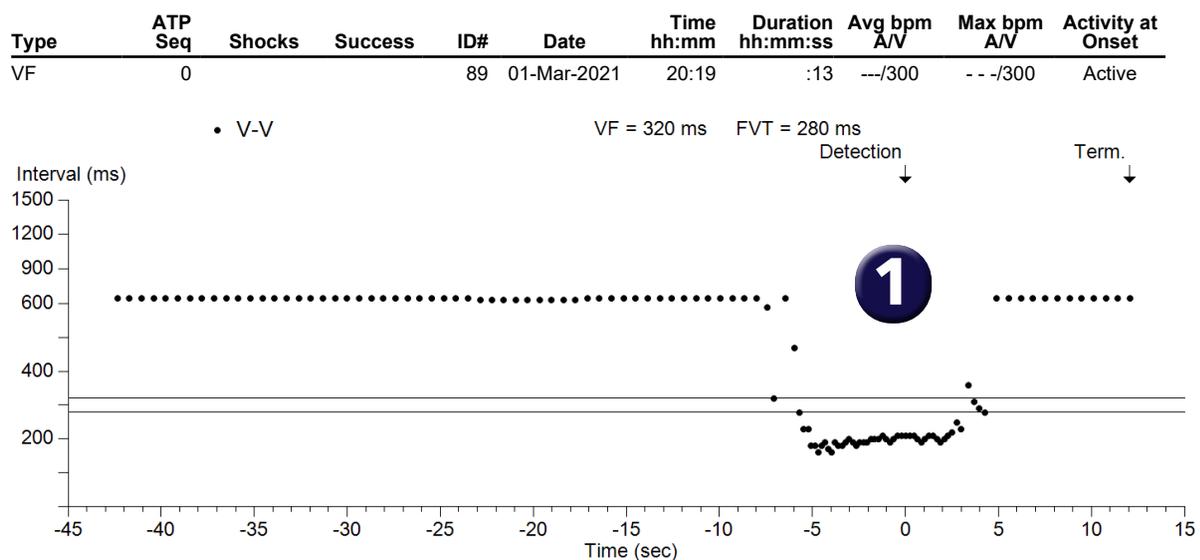
Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	0			89	01-Mar-2021	20:19	:13	---/300	- - -/300	Active

1 What diagnosis is suggested by the interval plot?

The plot shows a sudden acceleration of the ventricular rate with cycles detected in the VF zone; the initial VF counter is filled (Detection) but no therapy is delivered following probable spontaneous reversion.

23

EGM3: LVtip to RVcoil
(10 mV)

EGM2: Can to RVcoil
(1 mV)

Markers

V-V Interval (ms):

| B V | | B V | | B V | | B V | | B V | | B V | | B V | | V S | | V S |
| 6 5 0 | | 6 5 0 | | 6 5 0 | | 6 5 0 | | 6 5 0 | | 6 5 0 | | 5 9 0 | | 3 2 0 |

| V | B V | | V | T S | F | F | F S | F | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F S | F |
| 6 5 0 | 4 7 0 | 2 8 0 | 2 3 0 | 2 3 0 | 1 8 0 | 1 6 0 | 1 8 0 | 1 9 0 | 1 7 0 | 1 6 0 | 1 9 0 | 1 8 0 | 1 8 0 | 1 9 0 | 1 8 0 | 1 9 0 | 1 9 0 | 2 0 0 | 1 0 0 | 1 0 0 | 1 1 0 | 1 9 0 | 1 0 1 | 1 1 | 1 |

| F DI VF VF Rx 1 Defib | V S | V S | V S | V S | V S | V S | V S | V S | V S | V S | V S | V S | V S | V S | V S | V S | V S | V S | B V | B V | B V | B V |
| 2 1 0 | 2 1 0 | 2 0 0 | 1 9 0 | 2 0 0 | 2 1 0 | 2 0 0 | 1 9 0 | 2 0 0 | 1 2 0 | 2 5 0 | 3 3 0 | 3 6 0 | 2 1 0 | 2 9 0 | 2 8 0 | 6 5 0 | 6 5 0 | 6 5 0 | 6 5 0 |

Aborted

| B V | | B V | | B V | | B V | | B V | | B V | | B V | | B V |
| 6 5 0 | | 6 5 0 | | 6 5 0 | | 6 5 0 | | 6 5 0 | | 6 5 0 | | 6 5 0 | | 6 5 0 |

Termination

❷ What type of arrhythmia is it

This is probably a very rapid ventricular arrhythmia.

❸ How is the initial detection counter in the VF zone programmed?

The initial counter is set to 30/40.

❹ What does aborted mean?

Charging of the capacitors starts when the initial VF counter is filled; during charging, the arrhythmia stops spontaneously and after 4 consecutive cycles classified as BV, charging is interrupted (discontinuation of therapy).
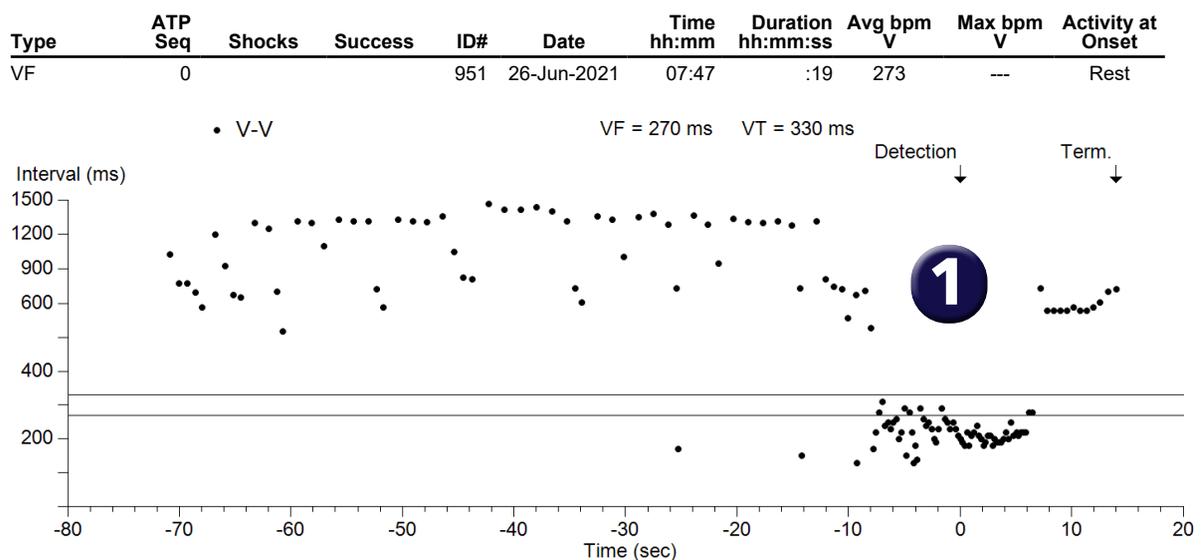
Key messages

- This episode corresponds to polymorphic ventricular tachycardia which resolves spontaneously after about ten seconds.

- This patient had multiple episodes of non-sustained ventricular tachycardia stored in the device's memory; these are defined by at least 5 consecutive cycles in one of the detection zones without any counters being filled (VT or VF) and a few episodes, like this example, where the counters were filled but charging was interrupted.

- Programming the number of cycles in the initial counter is crucial for the patient's quality of life and prognosis; today, it is recommended that the initial counter in the VF zone is programmed for 30/40 cycles as a first-line treatment; results from a large number of patients have shown that this programming significantly reduces the number of inappropriate therapies (expected result) but also the number of appropriate but avoidable therapies, when the arrhythmia terminates spontaneously.

5 increasing counters and preventing avoidable therapies

Patient

Patient implanted with a single-chamber defibrillator (Visia AF XT VR) for congenital long QT syndrome; episode of syncope.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VF	0			951	26-Jun-2021	07:47	:19	273	---	Rest

1 What diagnosis is suggested by the interval plot?

The plot shows a sudden acceleration of the ventricular rate with irregular cycles detected in the VF zone; the initial VF counter is filled (Detection) but no therapy is delivered following probable spontaneous reversion.
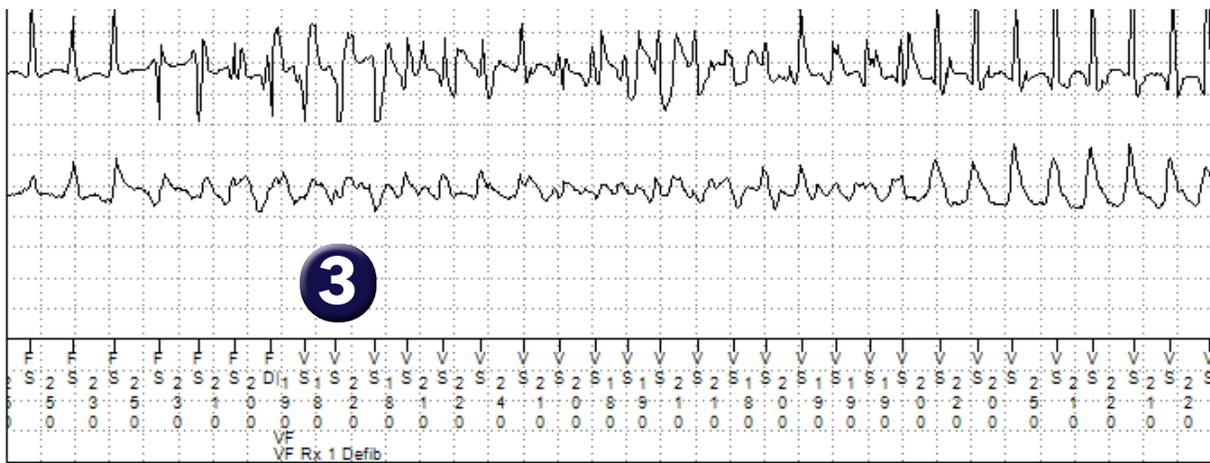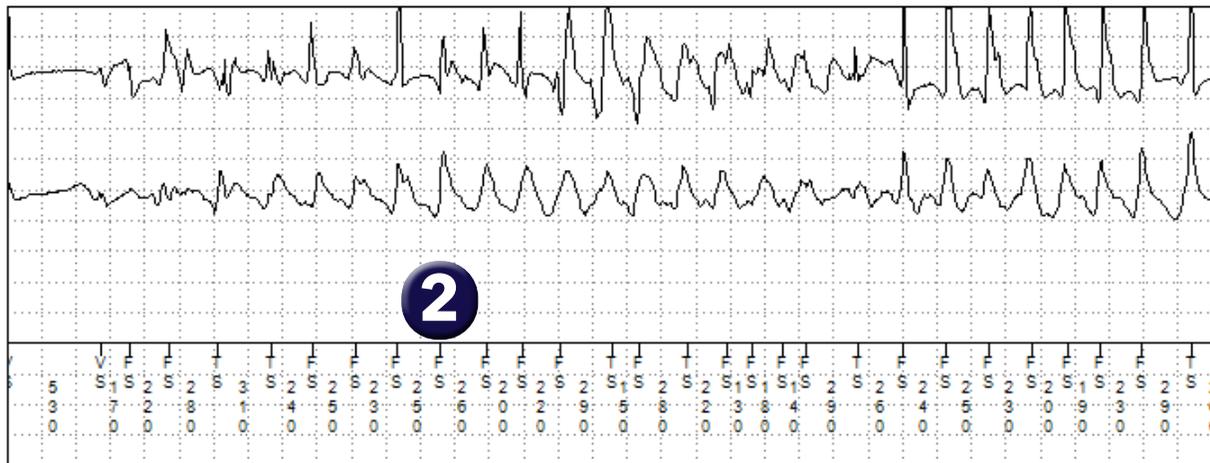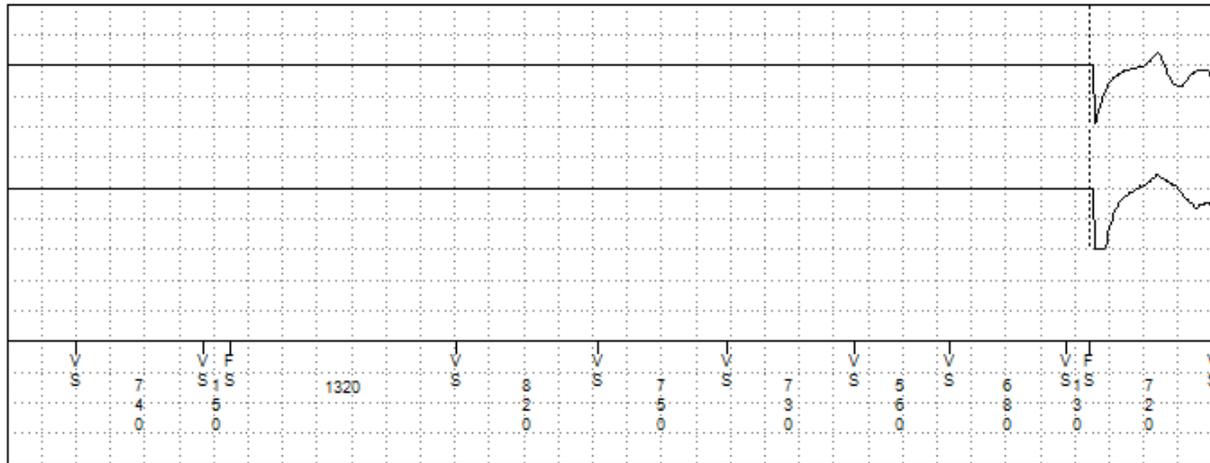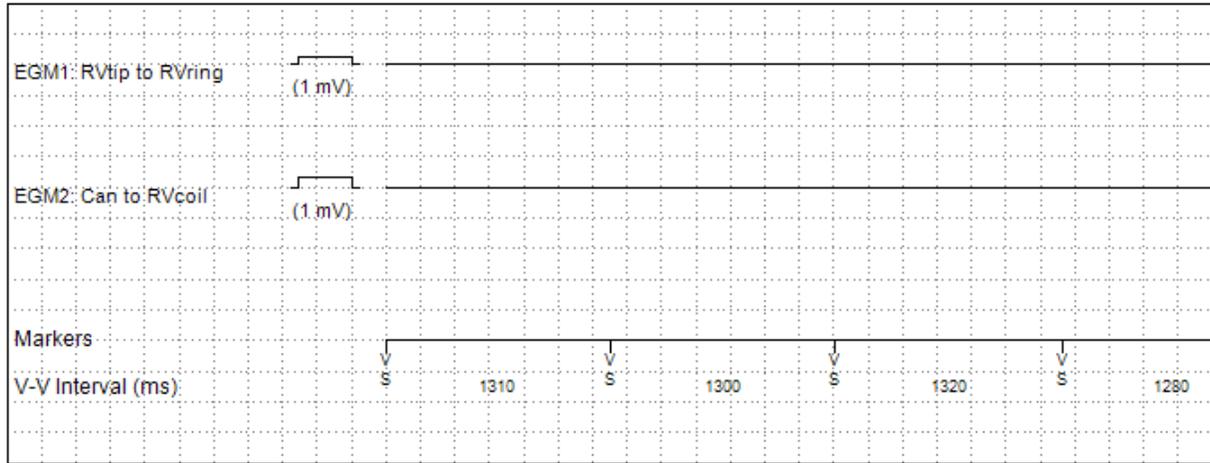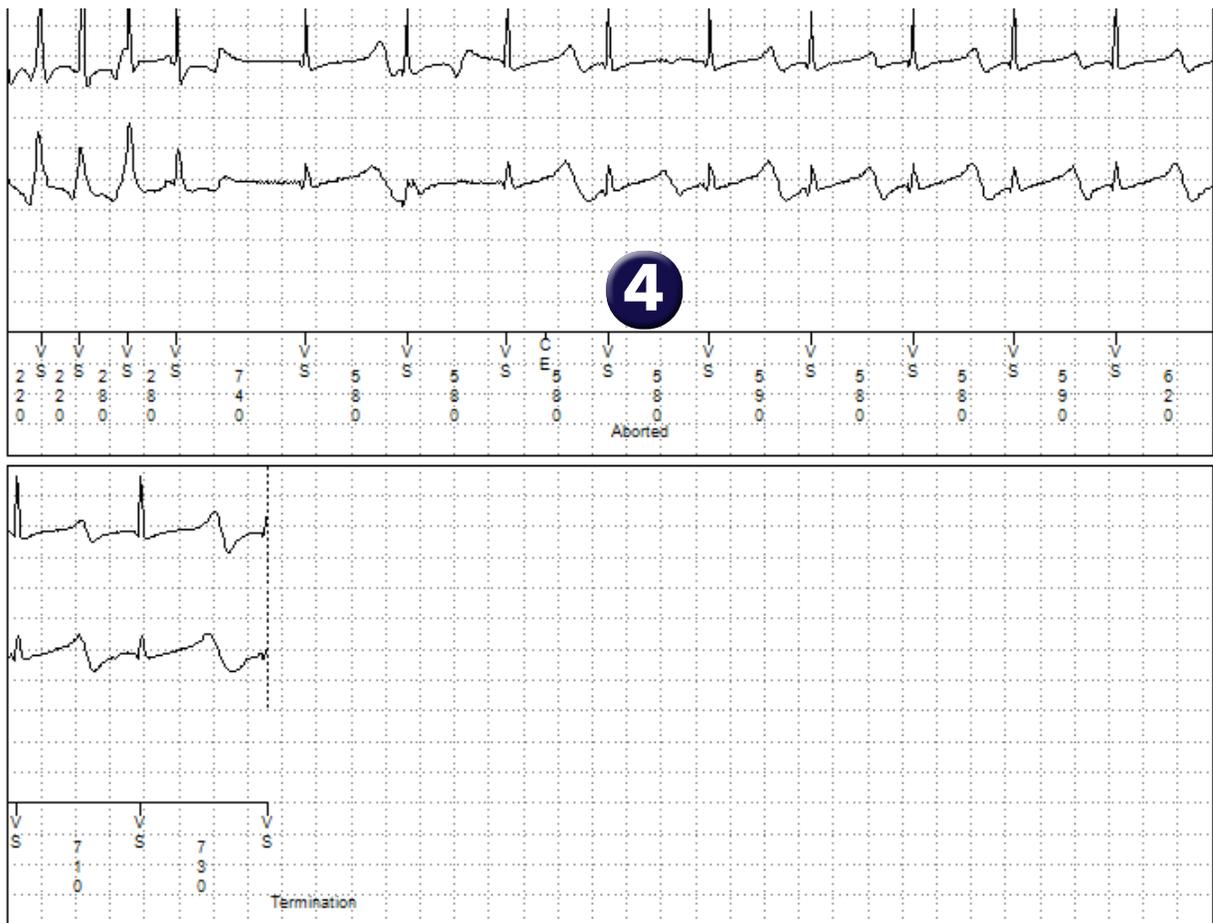
2 What type of arrhythmia is it?

This is probably a very rapid and irregular ventricular arrhythmia; the shock channel shows the polymorphic character with a torsades-like appearance.

3 How is the initial detection counter in the VF zone programmed?

The initial counter is set to 30/40.

4 What does aborted mean?

The capacitors start charging when the initial VF counter is filled; during charging, the arrhythmia stops spontaneously and after 4 consecutive slow cycles, the therapy is abandoned; note that the shock channel makes it possible to identify a very long QT interval

Key messages

- This episode of arrhythmia corresponded to torsade de pointes which lasted around fifteen seconds and terminated spontaneously with an aborted charge at the end of the charging; this tracing illustrates the importance of the confirmation phase during and at the end of charging to avoid delivering a shock when the tachycardia has terminated.

- One of the main objectives of defibrillator programming is to reduce, as far as possible, the number of inappropriate or avoidable therapies; the systematic programming of an initial counter at 30/40 is a step towards this objective; in the VF zone, the initial counter is filled after approximately 7 to 8 seconds; if we add the charging time and confirmation at the end of the charge, the total time in arrhythmia is at least 15-17 seconds before delivering a shock, which allows spontaneous reversion.

- Treating an episode of malignant ventricular arrhythmia with a shock remains the only option for restoring viable haemodynamics; however, latest recommendations advise avoiding treating ventricular arrhythmias prematurely and too aggressively, because they can terminate spontaneously; a shock can save a life but has its own deleterious effects and should be avoided wherever spontaneous reversion is possible or less aggressive therapies may be effective.

- It is therefore advisable: 1) not to systematically program treatment zones that are too low for primary prevention; 2) to lengthen the initial detection counters not only in the VT zone, but also in the VF zone, to avoid treating episodes of arrhythmia that would have reverted spontaneously (appropriate but avoidable therapies); 3) to favour first-line treatment with anti-tachycardia pacing, even for very rapid tachycardias (limit of 230-250 beats/minute).

6 initial counter and redetection counter

Patient

Patient implanted with a dual-chamber defibrillator (Evera XT DR) for ischaemic cardiomy-opathy; hospitalisation for syncope.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	0	35J, 35J	Yes	35	26-Jul-2018	19:59	:31	64/286	- - -/286	Rest
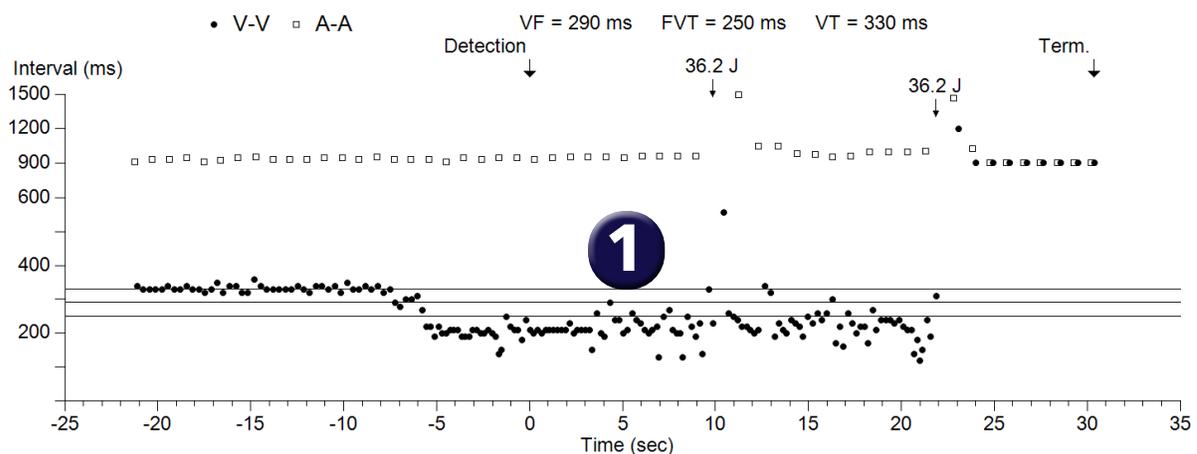
1 What diagnosis is suggested by the interval plot?

Three detection zones are programmed; initially, the plot suggests the presence of VT (atrioventricular dissociation) at the lower limit of the VT zone; in a second phase, the ventricular rhythm accelerates with irregular cycles in the VF zone; a first maximum output shock is delivered but does not terminate the arrhythmia; a second maximum output shock appears effective; the diagnosis is therefore VT degenerating into VF requiring 2 shocks.

2 What is your diagnosis?

The tracing shows a rapid, polymorphic ventricular arrhythmia consistent with VF.

3 How does the device work at the end of this first charge?

It is set to 30/40; the TF. and FS cycles implement the same counter.

EGM1: Atip to Aring

(1 mV)

EGM3: RVtip to RVring

(1 mV)

A-A Interval (ms)

Markers

V-V Interval (ms)

31
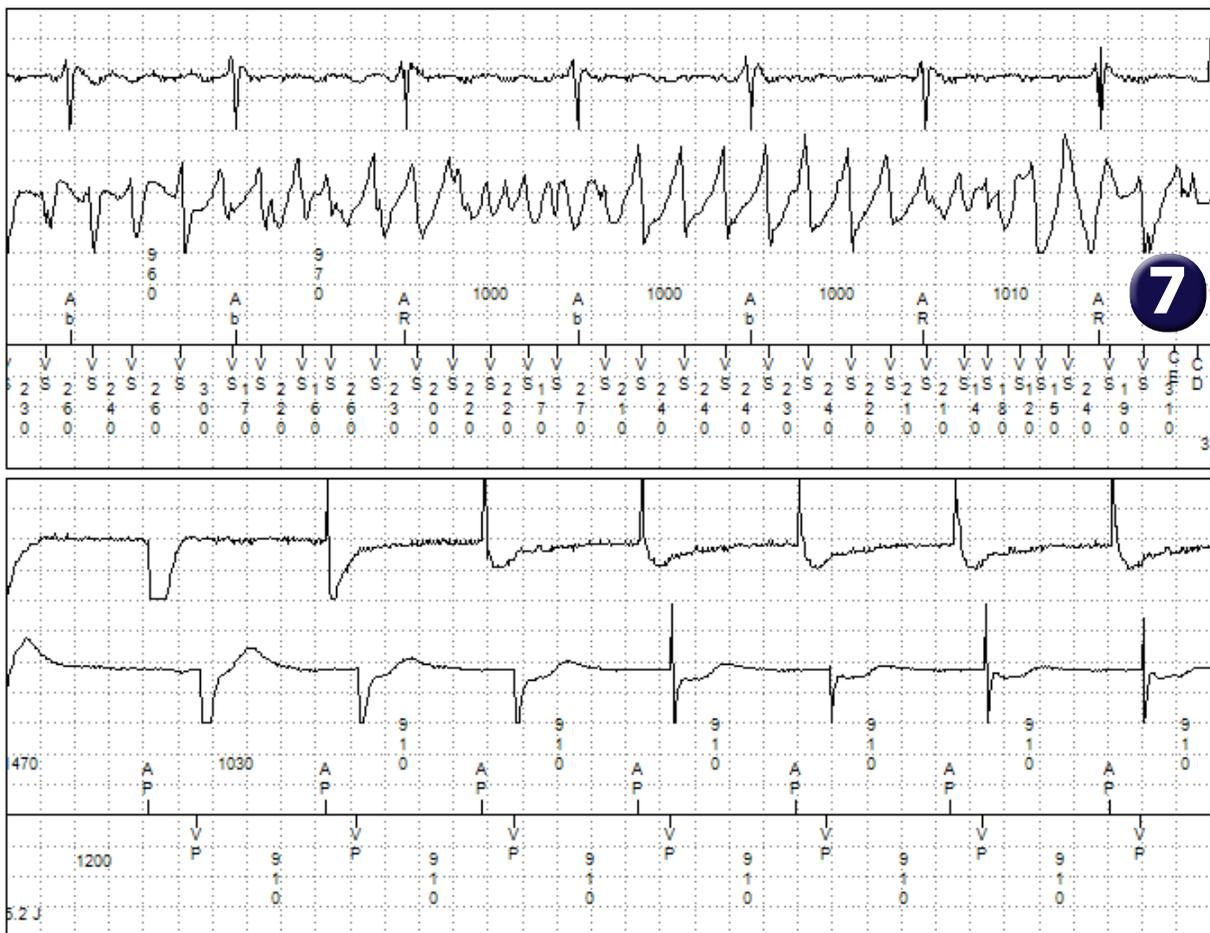
4 How does the device work at the end of this first charge?

The shock is said to be "non-committed", so there is a confirmation phase; the shock is delivered on the second rapid cycle following the CE marker.

5 What was the effect of the shock?

The shock was ineffective and the arrhythmia persisted.

6 What does the FD marker mean?

The redetection counter programmed to 12/16 is filled; following the shock, 12 cycles are classified as FS and 2 cycles are classified as VS.

7 How does the device work at the end of this second charge?

The second shock of the same episode is said to be "committed", i.e. it is committed to being delivered if the re-detection counter has been filled; at the end of the charge (CE), the device synchronises to the first sensed QRS complex.

Key messages

- This VF trace is used to discuss the operation of the defibrillator once the first shock has been delivered.

- A blanking phase of 520 ms, during which no sensing is possible, occurs systematically following all shocks to avoid oversensing of the polarisation induced by the shock.

- The device must then differentiate between 1) termination of the episode and 2) an ineffective shock with continuation of the arrhythmia and competition between 2 counters: I) the redetection counter which is programmable; like the initial counter, this is a probabilistic counter with a threshold of 75% short cycles (6/8, 9/12 ... 30/40); the number of cycles required applies to all subsequent shocks (from 2 to 6) during the same episode; it is usual to program a lower number of cycles required for redetection than for initial detection, as the risk of undersensing increases with the duration of the arrhythmia; II) the end-of-episode counter which is based on 2 criteria: a) the device diagnoses the end of the episode when 8 consecutive VS or VP cycles slower than the lowest programmed detection zone (VF or VT) are recorded; b) it also diagnoses the end of the episode if, for 20 seconds, the median of 12 consecutive cycles is slower than the lowest programmed detection zone (VF or VT).

- It should be noted that once the redetection counter has been filled, the shock will be automatically delivered at the end of the charge by synchronising with a sensed complex or asynchronously if no complex is detected («committed» shock; no confirmation phase at the end of the charge).

33

7 no confirmation for a second shock

Patient

Male implanted with a single-chamber defibrillator (Visia AF XT VR) for ischaemic cardio-myopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VF	2	35J, 35J	Yes	4	12-Apr-2022	14:52	:36	222	222	Active
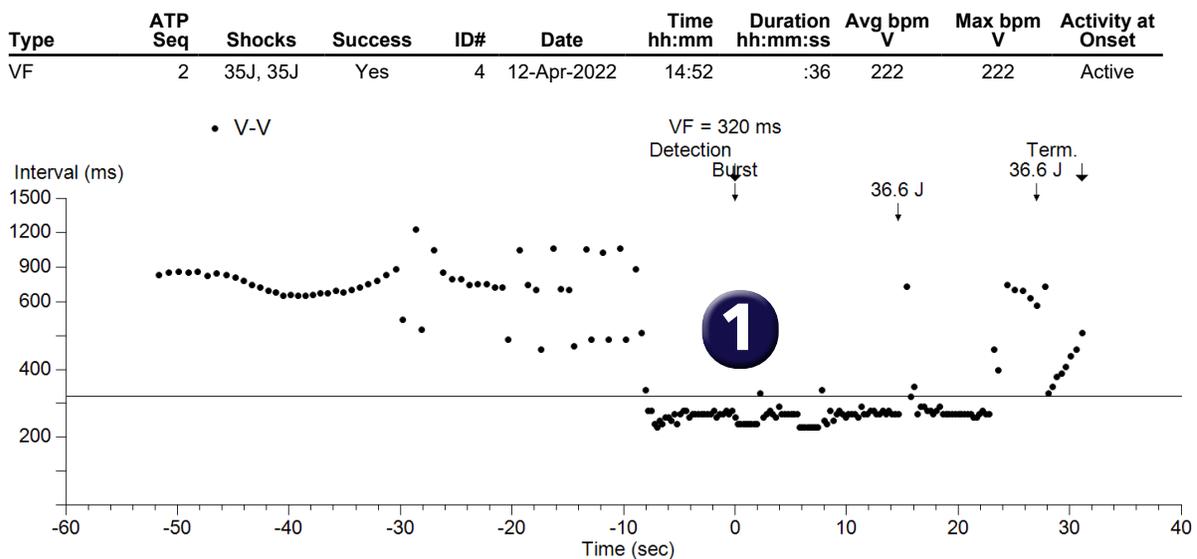
1 What diagnosis are you suggesting on this graph?

The plot shows a sudden acceleration of the ventricular rhythm with rapid cycles detected in the VF zone; a burst and then a shock are delivered; the first shock seems ineffective with persistence of the arrhythmia which terminates in a second phase; a second shock is delivered just as the rate seems to have normalised.

2 What is your diagnosis?

The tracing shows a rapid, monomorphic ventricular arrhythmia detected in the VF zone.

3 What therapy is delivered?

This is a burst before the charge.

EGM1: RVtip to RVring
(1 mV)

EGM2: Can to RVcoil
(1 mV)

Markers
V-V Interval (ms)

VF Rx 1 Burst Before Charging

VF
VF Rx 1 Burst During Charging

VF Rx 1 Defib
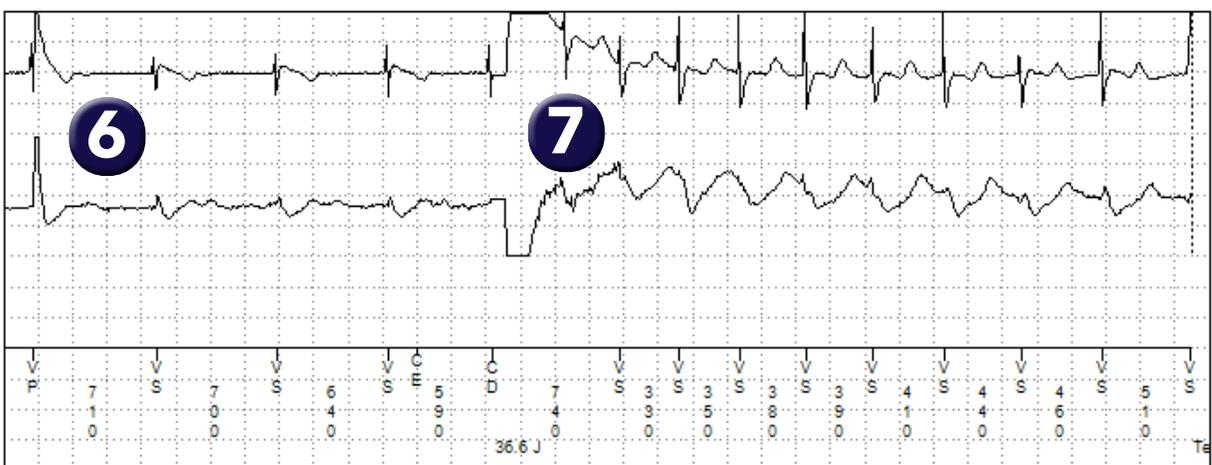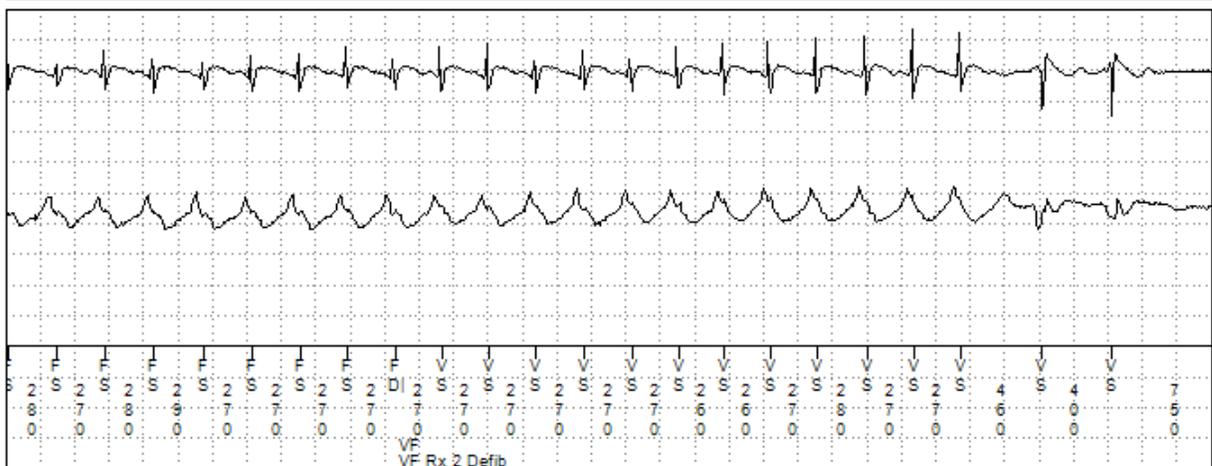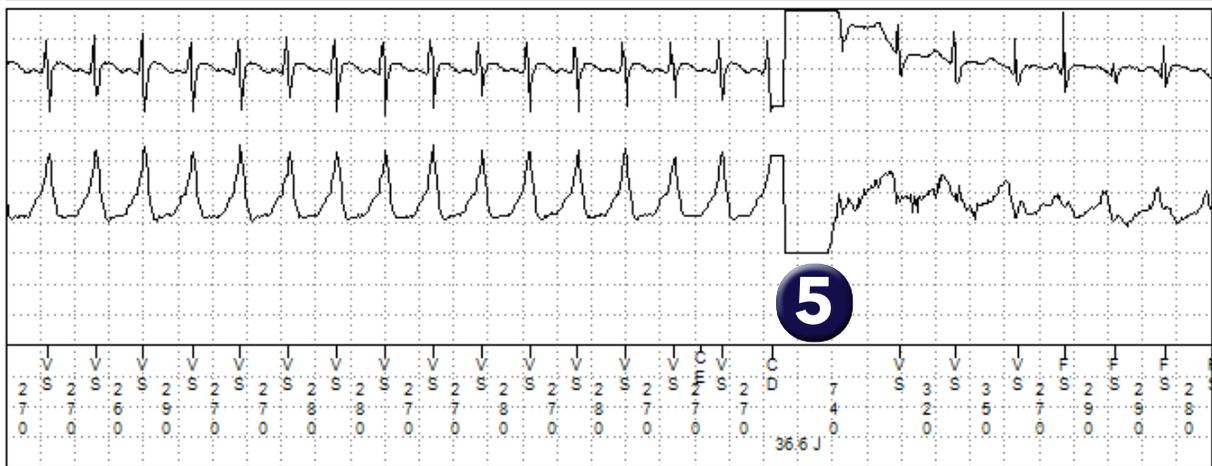
4 What therapy is delivered?

This is a burst during the charge, the first burst having been ineffective.

5 What therapy is delivered?

This is a maximum output shock delivered when the 2 bursts have proved ineffective.

6 What is the effect of the shock?

The shock was ineffective and a monomorphic ventricular arrhythmia persisted; the redetection counter was filleded (12/16).

7 How do you explain the delivery of this second shock?

The ventricular arrhythmia has spontaneously terminated during charging; once the re-detection counter was filled, therapy (second shock) cannot be abandoned; at the end of charging, the device synchronises with the first ventricular complex detected and the shock is delivered.

Key messages

- In the VF zone, the defibrillator operates differently between the first shock in a series and any subsequent shocks (shocks 2 to 6).

- For the first shock, charging can be interrupted or abandoned; following initial detection, charging can be interrupted if the arrhythmia terminates spontaneously during charging (evidence of at least 4 slow cycles out of 5); similarly, if the arrhythmia terminates spontaneously at the end of charging, the charge can be abandoned (evidence of at least 4 slow cycles out of 5 after the CE marker).

- Conversely, for shocks 2 to 6, when the redetection counter is filled, charging can no longer be interrupted or abandoned and the shock will be systematically delivered, with an attempt to synchronise to a ventricular sensed event at the end of the charge; in fact, if the redetection counter was filled, the device considers that the shock was ineffective and starts charging the capacitors; if it diagnoses reversion when charging has begun, the shock is still delivered at the end of charging ; this is to avoid withholding essential therapy in the event of under-sensing that can result in an incorrect diagnosis of arrhythmia termination.

8 specifics of the VT counter

Patient

Patient implanted with a single-chamber defibrillator (EnTrust VR) for dilated cardiomyopathy and hospitalised for palpitations; 3 detection zones were programmed with a VT zone between 400 and 320 ms.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VT	1		Yes	43	19-Jun-2005	21:32	:06	188	188	Active

• V-V   VF = 320 ms   FVT = 280 ms   VT = 400 ms
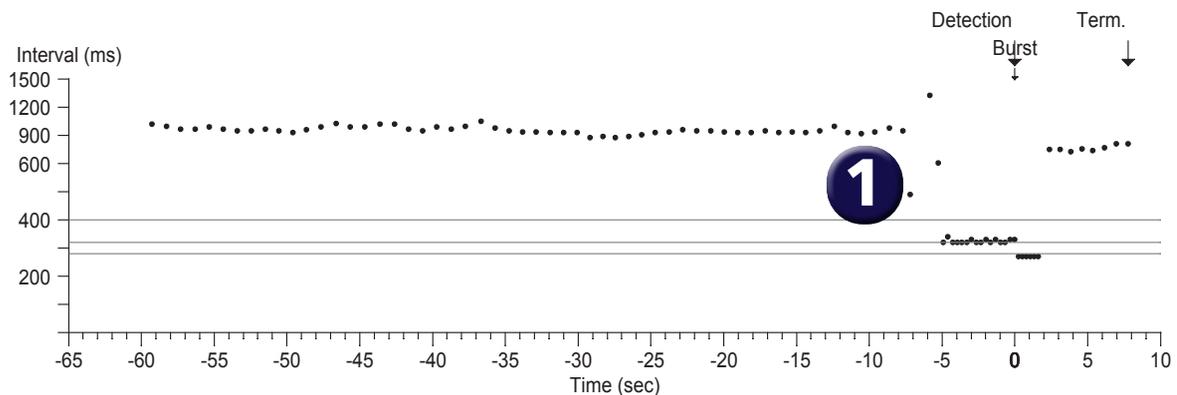
1 What diagnosis are you suggesting on this graph?

The plot shows an initial rhythm that appears normal, followed by sudden acceleration, and detection of a regular tachycardia in the VT zone that is effectively treated by a burst of anti-tachycardia pacing.

2 What is your diagnosis?

Probable VT; on the EGM, there is sudden acceleration with a regular tachycardia where all cycles are detected in the VT (TS) zone.

3 What therapy is delivered?

After 16 consecutive cycles classified as TS, the device diagnoses VT; a burst is delivered; it is effective with return to sinus rhythm followed by an end-of-episode diagnosis (Termination) after 8 consecutive cycles classified as VS.

EGM1: Vtip to Vring............ (1 mV)

EGM2: Can to HVB............. (1 mV)

Markers.

V-V (ms):

	V-S		V-S		V-S		V-S		V-S		V-S
	950		1000		930		920		940		980

V-S		V-S		V-S		V-S		V-S		T-S	T-S	T-S	T-S	T-S	T-S	T-S	T-S	T-S	T-S
950		490		1330		610		320		340	320	320	320	320	330	320	320	330	320

T-S	T-S	T-S	T-S	T-S	T-D	T-P	T-P	T-P	T-P	T-P	T-P	V-S	V-S	V-S	V-S	V-S
330	320	320	330	330	270	270	270	270	270	750	750	750	760	740

VT

	V-S		V-S		V-S
770		810		810	

Termination

39
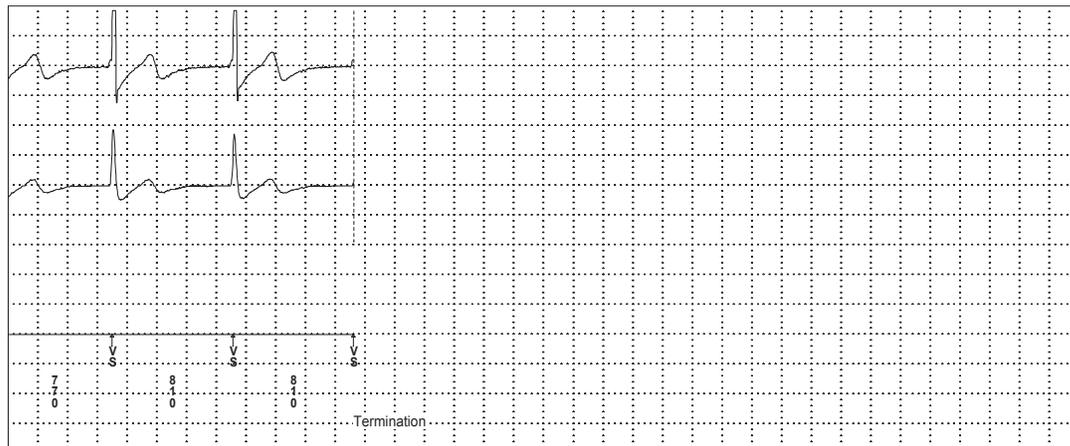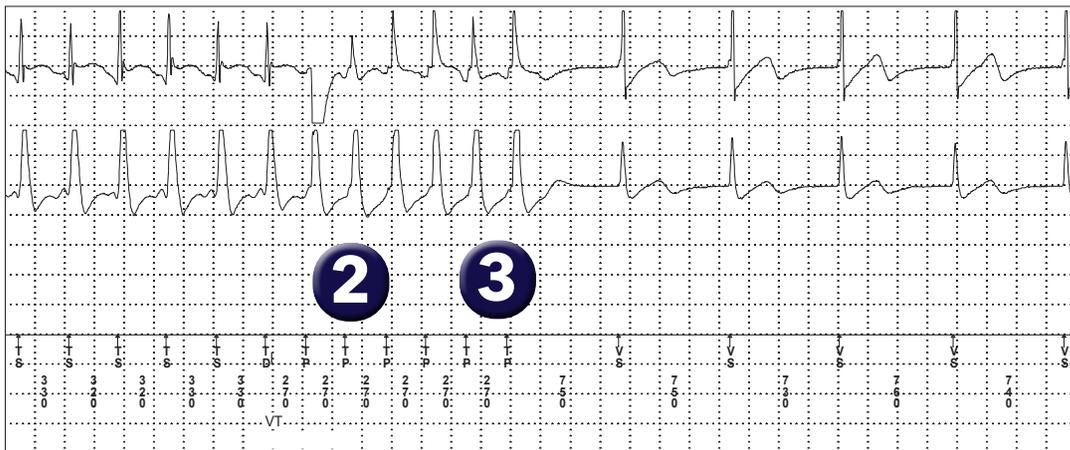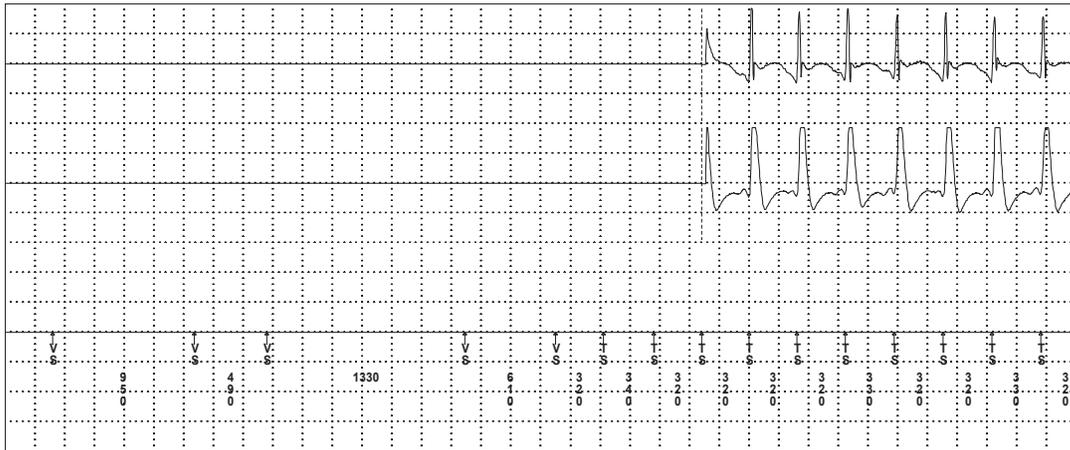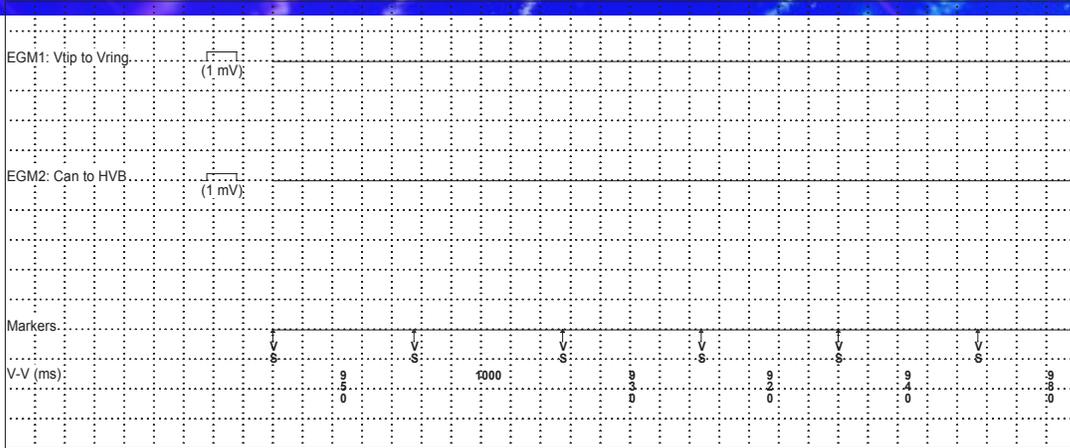
Key messages

- The specific features of the VT counter must be perfectly integrated to allow optimum programming; in fact, for Medtronic™ devices, the method of counting differs completely between the VT zone (consecutive cycles) and the VF zone (probabilistic counter), which is not the case for other vendors' defibrillators.

- A cycle classified in the VT zone increments the VT counter by +1; a cycle classified in the VF zone does not modify the VT counter (no increment, no decrement); a long cycle classified as VS resets the VT counter to 0.

- This counter has been specifically developed to provide optimal performance for tachycardias with a rate less than 200 beats/minute, with a dual objective: 1) to effectively detect episodes of regular, monomorphic ventricular tachycardia; 2) to provide a first level of «discrimination» during an episode of atrial fibrillation, which often includes one or more slow cycles that reset the counter to 0.

- The VT counter is filled after a programmable number of consecutive cycles falling in the VT zone (VF cycles do not modify the counter); a single cycle classified as VS resets the VT counter to 0, which has several consequences: 1) inappropriate resetting of this counter to 0 can occur following ventricular under-sensing (common in polymorphic ventricular tachycardias); this counter is probably inappropriate for tachycardias greater than 200 beats/minute which include polymorphic arrhythmias with signals of variable amplitude; 2) this counter improves the specificity of diagnoses, an episode of atrial fibrillation being frequently associated with repeated long cycles (frequent return of the counter to 0).

9 AF and the VT counter

Patient

Patient implanted with a dual-chamber defibrillator (Evera XT DR) for ischaemic cardio-myopathy presenting with multiple episodes of paroxysmal atrial fibrillation; 2 detection zones were programmed with a VT zone between 350 and 270 ms.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
SVT-AF				55	21-Sep-2015	10:28	:02:50	400/231	462/---	Active

• V-V   □ A-A   VF = 270 ms   VT = 350 ms

VT/VF Detection Withheld   Term.
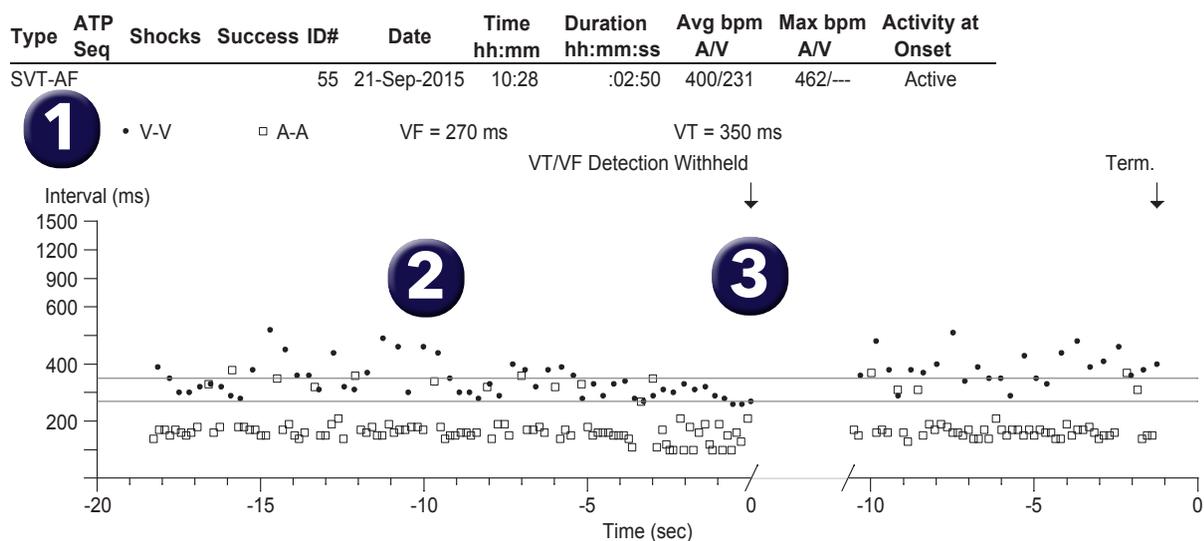
What diagnosis is suggested by the interval plot?

The episode was diagnosed as SVT/AF by the device (1); the interval plot initially shows a very rapid and irregular atrial rhythm associated with a rapid and irregular ventricular rate (alternating cycles detected in and out of the VT zone) compatible with an episode of conducted AF (2); in a second phase, the ventricular rate stabilises in the VT zone; the VT counter is filled but no therapy is delivered (3).

41

EGM1: Atip to Aring.

(1 mV)

EGM3: RVtip to RVring.

(1 mV)

A-A (ms):

Markers.

V-V (ms):

The EGM strip shows markers with values including: 150 AS, 180 AD, 370 AR... with VS, TS markers and interval numbers (350, 330, 440, 480, 390, 410, 460, 360, 380, 400) and a "Termination" annotation.

4 What is your diagnosis?

On the EGM, there is very rapid and irregular atrial activity in favour of atrial fibrillation, as well as irregular ventricular cycles classified as either VT or VS; the VT counter is repeatedly reset to 0 following the detection of ventricular cycles classified as VS.

5 How does the tachycardia develop?

The ventricular rate accelerates and stabilises in the VT zone.

6 How do you explain the fact that no therapy is delivered?

The VT counter is filled after 16 TS cycles and 2 FS cycles (counter programmed at 16, FS cycles do not modify the VT counter); no therapy is delivered, the PR Logic discrimination algorithm leading to a diagnosis of AF.

43

Key messages

- This tracing demonstrates the usefulness of the Medtronic™ VT counter in preventing inappropriate therapies during an episode of conducted AF; this patient had multiple episodes of relatively rapid conducted AF which were not stored in the device memory, the presence of repeated long cycles allowing the VT counter to return to 0, thereby preventing the counter from being filled and the episodes from being stored; in rare cases, as in this trace, the ventricular rhythm stabilises in the VT zone, with PR Logic providing effective discrimination and preventing inappropriate therapies.

- This specificity is a major advantage of this type of counter; the risk of inappropriate therapies for atrial fibrillation is significantly reduced, especially since there has been a trend in recommendations towards increasing the number of cycles required to diagnose VT; for an AF episode occurring at a rate corresponding to the VT zone to result in inappropriate therapies, a combination of the following is required: 1) a number of consecutive cycles in the VT zone (30 in the new recommendations) without any long cycle classified as VS, which is relatively rare when the lower limit of the VT zone is programmed between 150 and 160 beats/minute; in fact, a single cycle classified as VS resets the VT counter to 0; 2) a discrimination error by PR Logic and Wavelet which operate in a second phase and can correct a diagnostic error; this explains why the risk of inappropriate therapies for conducted AF falling in the VT zone is relatively low.

10 zone limits and the VT counter

Patient

Male implanted with a dual-chamber defibrillator (Evera XT DR) for dilated cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VT-NS				81	05-Jun-2019	20:40	:03	90/182		Active

• V-V   □ A-A   VF = 270 ms   VT = 340 ms
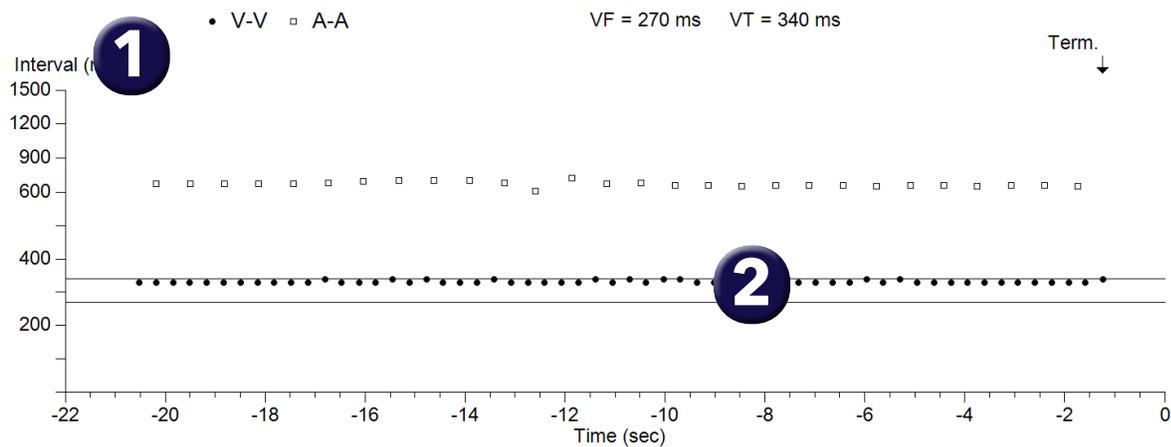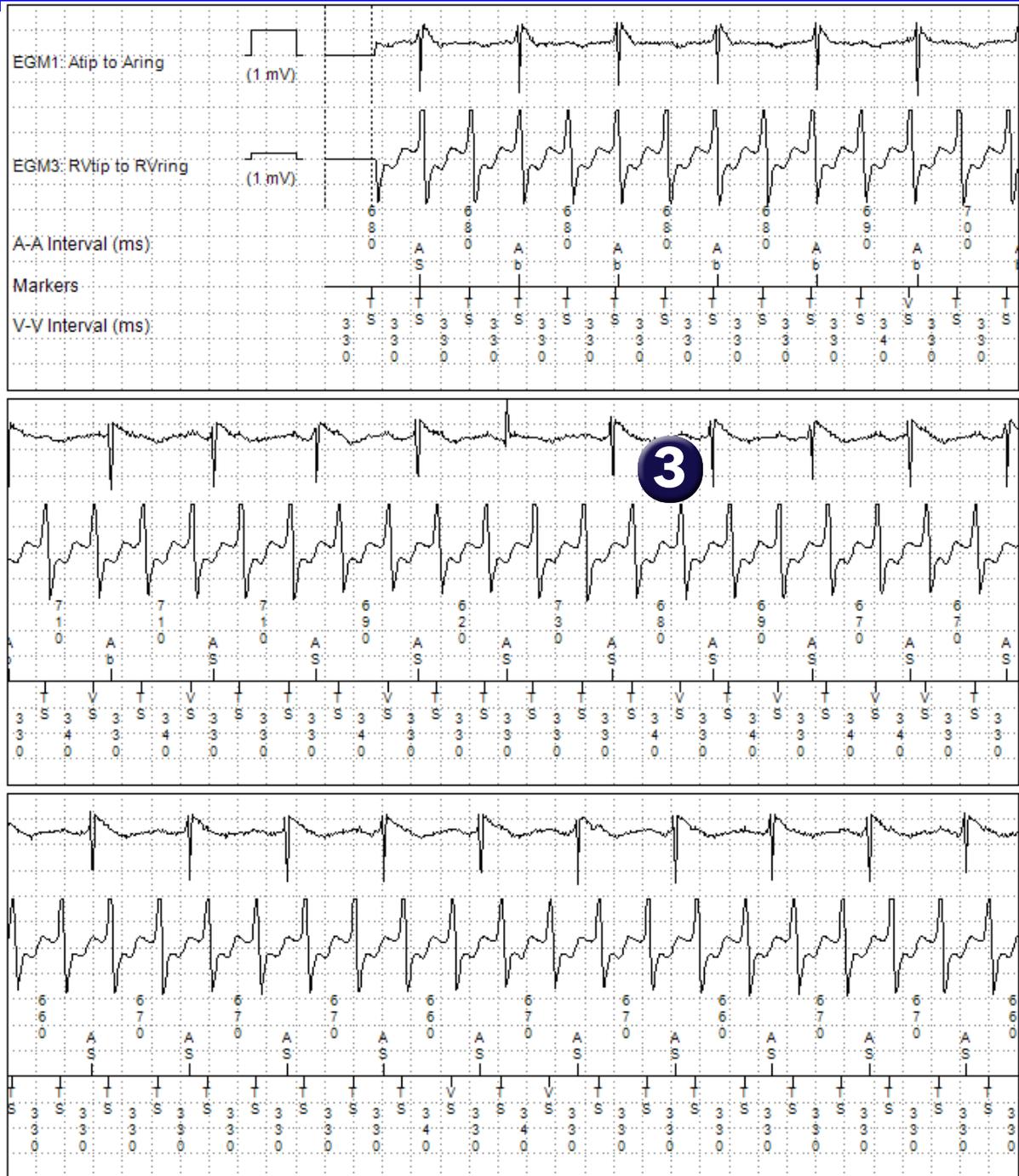
1 2 What diagnosis is suggested by the interval plot?

The episode was classified as VT-NS by the device (1); the plot shows atrioventricular dissociation with cycles oscillating around the VT zone (2).

❸ What is your diagnosis?

The EGM shows VT (ventricular rate > atrial rate); some cycles are classified as TS, others as VS; cycles classified as VS reset the VT counter to 0.

Key messages

- This plot shows one of the possible limitations of the VT counter, which requires a programmable number of consecutive cycles classified as TS, and highlights the importance of programming the lower limit of the VT zone.

- In this patient, the diagnosis of VT is indisputable, with obvious atrioventricular dissociation; however, there is a delay in diagnosis due to specificity in the operation of this counter; the tachycardia oscillates around the lower limit of the VT zone; when a cycle is classified as VS, the VT counter is reset to 0 even if, as in this case, the diagnosis of VT is obvious.

- It is therefore essential to program a sufficient margin based on the rate of the clinical tachycardia to avoid this type of problem; it is usual to program the VT zone 10 to 20 beats/minute slower than the clinical VT, this margin should probably be slightly higher for Medtronic™ devices, since the occurrence of a cycle classified as VS has different consequences compared to defibrillators of competing devices.

- This specificity also means that VT counters are generally not used for tachycardias above 200 beats/minute, as the risk of intermittent undersensing is increased (more frequently with polymorphic tachycardias), resulting in delayed or non-diagnosis and delayed or withheld treatment; the probabilistic VF counter seems more appropriate for this type of tachycardia.

- In the latest recommendations, there are marked differences in terms of programming the detection zone boundaries depending on the manufacturer; the different operation of the counters explains some of these differences (in primary prevention, Medtronic™ recommends a single VF zone from 188-200 beats/minute, compared with a VT zone up to approximately 230 beats/minute followed by a VF zone for the other manufacturers).

11 specific features of the fast VT counter

Patient

Man implanted with a single-chamber defibrillator (Visia AF XT VR) for dilated cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
FVT	1		Yes	30	18-Jan-2023	21:30	:10	207	207	Rest

1 2 What diagnosis are you suggesting on this graph?

This episode was classified as FVT (1); the plot shows a sudden acceleration with cycles detected mainly in the FVT zone; (2) detection of a FVT episode effectively treated with a burst.

③ What is your diagnosis?

The EGM shows a regular, monomorphic tachycardia, detected in the FVT zone; the TF. marker indicates that the defibrillator is programmed with a FVT via VF zone.

Episode #30: 18-Jan-2023 21:30:47

Episode Summary		Initial VT/VF Detection
		Withheld By
Initial Type	FVT (spontaneous)	
Duration	10 sec	None
V. Max Rate	207 bpm	
V. Median	207 bpm (290 ms)	
Activity at onset	Rest, Sensor = 43 bpm	
Last Therapy	FVT Rx1: Burst, Successful	

Therapies	Delivered	Charge	Ohms	Energy
FVT Rx 1 Burst	Seq 1			
|				
Termination				

Wavelet Measurements Prior to Initial VT/VF Detection

Wavelet Result:	VT/VF
Template Status:	Inconsistent with intrinsic rhythm

-8.	No Match	0 %
-7.	No Match	0 %
-6.	No Match	0 %
-5.	No Match	0 %
-4.	No Match	0 %
-3.	No Match	0 %
-2.	No Match	0 %
-1.	No Match	0 %
0.	Detection	

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	320 ms (188 bpm)
FVT	via VF			270 ms (222 bpm)
VT	Off	24	12	
Monitor	Off	32		

⑤

Wavelet		Other Enhancements	
Wavelet	On, Match = 70%	Stability	Off
Template	18-Jan-2023, Auto = On	Onset	Off
SVT V. Limit	260 ms	High Rate Timeout	
		VF Zone Only	Off
		TWave	On
		RV Lead Noise	On

Polarity	RV
Pace Polarity	Bipolar
Sense Polarity	Bipolar

EGM	Source	Range	Sensitivity	
EGM1	RVtip to RVring	+/- 8 mV	RV	0.3 mV
EGM2 (Wavelet)	Can to RVcoil	+/- 4 mV		

4 What therapy is delivered?

The VF counter was filled with 30 cycles out of 40 classified as TF; analysis of the 8 cycles preceding the diagnosis found only TF cycles with no FS cycle leading to the diagnosis of FVT; the first therapy in the FVT zone, a burst, was delivered; termination of the arrhythmia.

5 How many zones are programmed?

The way in which the zones are programmed can be difficult to understand; you might think that the VF zone starts at 188 bpm and stops at 222 bpm, with the FVT zone starting at 222 bpm; in fact the opposite is true: FVT from 188 to 222 bpm and VF above 222 bpm; the FVT zone is programmed via FV; this reflects the fact that the same VF counter is used for the FVT zone from 188 bpm.

Key messages

- When a FVT zone is programmed, it is possible to choose programming via VT or via VF; depending on the choice, the VT counter (consecutive cycles) or the VF counter (probabilistic) is used.

- As in this example, when a FVT zone is programmed via VF, the same FV counter is used for the FVT zone and the VF zone; therefore the TF and FS classified cycles implement the same probabilistic VF counter.

- When the VF counter is filled, the device analyses the last 8 intervals; if at least one of the intervals is classified as FS, the diagnosis is VF and the therapies in the VF zone are delivered; if none of the last 8 intervals is classified as FS, the diagnosis is FVT and the therapies in the FVT zone are delivered.

12 combined counter

Patient

Patient implanted with a single-chamber defibrillator (Visia AF XT VR) for dilated cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VF	1		Yes	11	24-Feb-2018	16:14	:13	222	---	Active
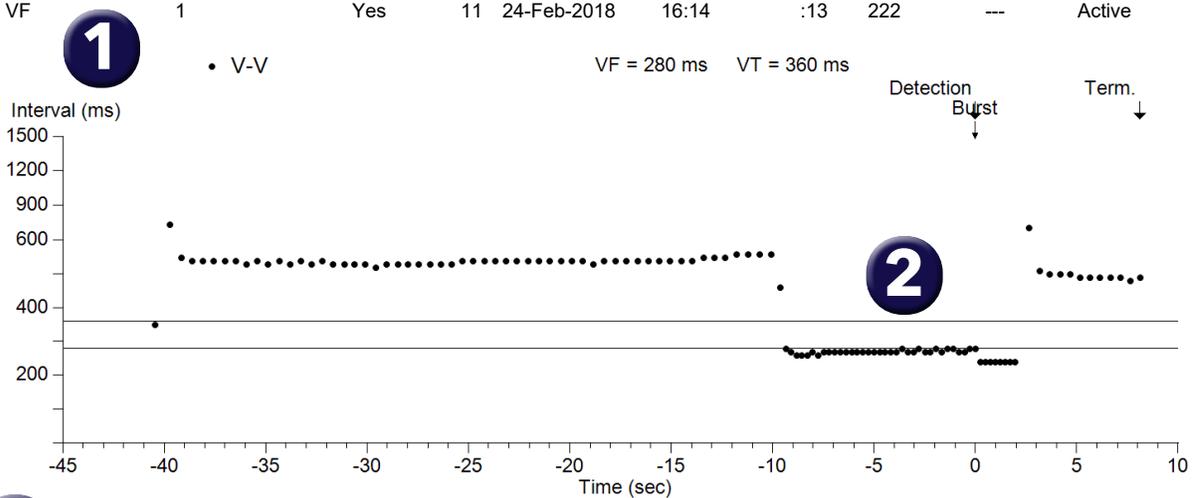
1 2 What diagnosis is suggested by the interval plot?

Two detection zones were programmed: a VT zone from 360 ms and a VF zone from 280 ms; this episode was classified as VF (1) by the device; the interval plot shows a sudden acceleration with cycles detected at the limit of the VF zone; detection of a VF episode effectively treated by a burst (2).

3 What is your diagnosis?

The EGM shows a regular, monomorphic tachycardia, with detection alternating between the VT and VF zones.
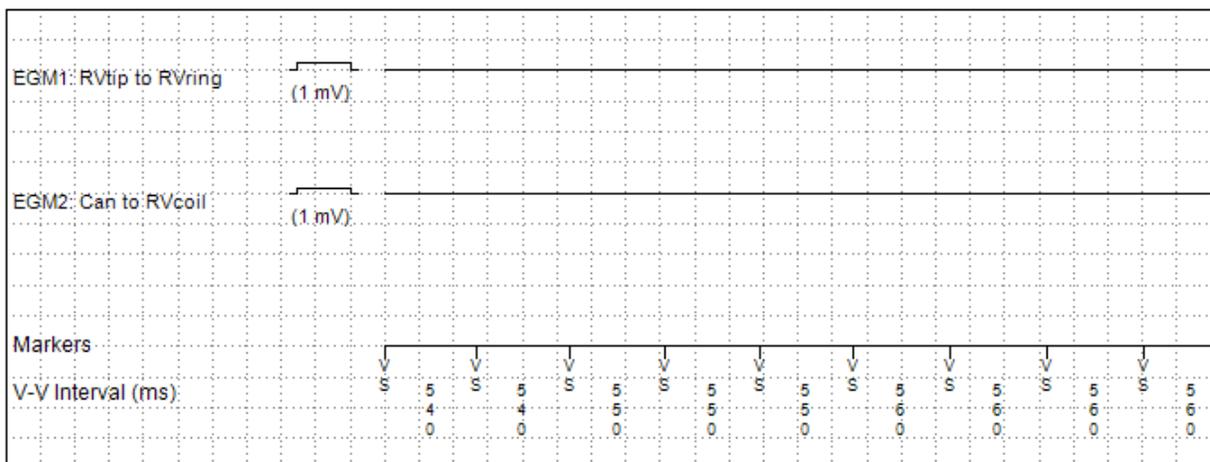
Episode #11: 24-Feb-2018 16:14:57

Episode Summary		⑤	Initial VT/VF Detection Withheld By
Initial Type	VF, via combined count (spontaneous)		None
Duration	13 sec		
V. Max Rate	---		
V. Median	214 bpm (280 ms)		
Activity at onset	Active, Sensor = 82 bpm		
Last Therapy	VF Rx1: Burst + Charging, Successful		

Therapies	Delivered	Charge	Ohms	Energy
Shock aborted because ATP During Charging terminated the rhythm.				
VF Rx 1 Burst	During Charging			
|				
VF Rx 1 Defib	Aborted	4.10 sec		35.0 J
|				
Termination				

Wavelet Measurements Prior to Initial VT/VF Detection

Wavelet Result:	VT/VF
Template Status:	OK

-8.	No Match	4 %
-7.	No Match	10 %
-6.	No Match	4 %
-5.	No Match	1 %
-4.	No Match	10 %
-3.	No Match	7 %
-2.	No Match	10 %
-1.	No Match	13 %
0.	Detection	

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	280 ms (214 bpm)
FVT	Off			
VT	On	16	12	360 ms (167 bpm)
Monitor	Off	32		

Wavelet		Other Enhancements	
Wavelet	On, Match = 70%	Stability	Off
Template	03-Jun-2017, Auto = On	Onset	Off
SVT V. Limit	260 ms	High Rate Timeout	
		VF Zone Only	0.75 min
		All Zones	Off
		TWave	On
		RV Lead Noise	On+Timeout
		Timeout	0.75 min

Polarity	RV
Pace Polarity	Bipolar
Sense Polarity	Bipolar

4   What therapy is delivered?

The combined counter was full, with 35 cycles classified as TS or FS (7/6 of 30 cycles); analysis of the last 8 cycles before diagnosis showed at least one cycle classified as FV leading to a diagnosis of VF; the first therapy in the VF zone, a burst during charging, was delivered with termination of arrhythmia.

5   What is the diagnosis made by the system?

The diagnosis is VF via the combined counter.

Key messages

- In a Medtronic™ defibrillator , the VT and VF counters operate independently, with a cycle classified as FS not incrementing the VT counter; this differs from the operation of some competitors' devices and can lead to a delay in diagnosis when an arrhythmia fluctuates between the VT and VF zones, as in this example.

- The combined counter has been designed to remedy this problem and is systematically active (cannot be programmed off) if a VT zone and a VF zone have been programmed.

- The combined counter is systematically triggered after the detection of 6 cycles classified as FS (essential prerequisite); the combined counter sums up the cycles classified as TS and FS and is filled when 7/6 (non-modifiable ratio) of the number of cycles required for initial detection in the VF zone have been detected; in this example, this parameter was programmed at 30/40, so the combined counter was filled after 35 cycles classified as TS or FS (7/6 of 30 = 35).

- When the combined counter is full, the device analyses the last 8 ventricular cycles; if at least one of these cycles is classified as FS, the device diagnoses VF and the first therapy in the VF zone is delivered; if the last 8 cycles are classified as TS, the device diagnoses VT and the first therapy in the VT zone is delivered.

13 fast VT and the combined counter

Patient

Male implanted with a dual-chamber defibrillator (Cobalt DR) for ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
FVT ①	1		Yes	50	04-Oct-2022	23:52	:12	88/188	---/188	Rest

• V-V Paced   ○ V-V Sensed   ▪ A-A Paced   □ A-A Sensed
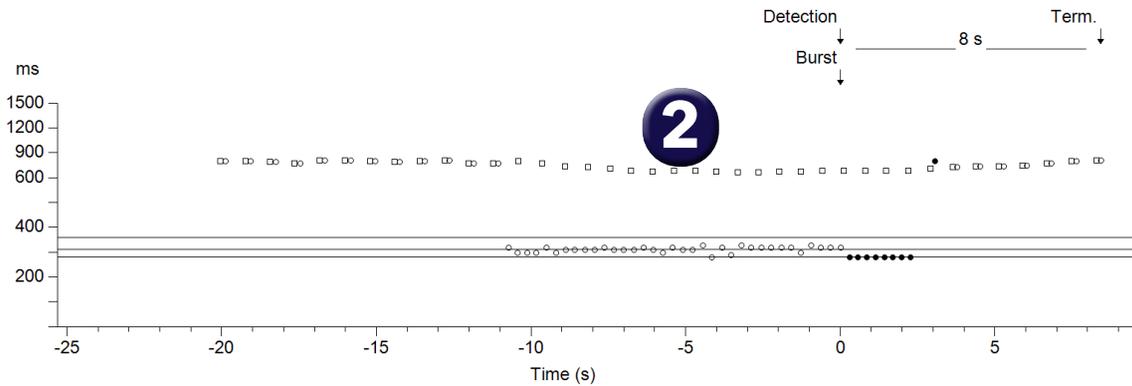
FVT = 280 ms   VF = 310 ms   VT = 360 ms

1 2 What diagnosis is suggested by the interval plot?

Three detection zones were programmed: a VT zone from 360 ms, a FVT zone from 310 ms and a VF zone from 280 ms; the episode was classified as FVT by the device (1); the plot shows probable VT with atrioventricular dissociation (2) with cycles oscillating between the limit of the VT-FVT zones; a burst is used to terminate the arrhythmia.

EGM1: Atip to Aring (1 mV)

EGM3: RVtip to RVring (1 mV)

A-A (ms)

Markers

V-V (ms)

FVT
FVT Rx1:Burst

③
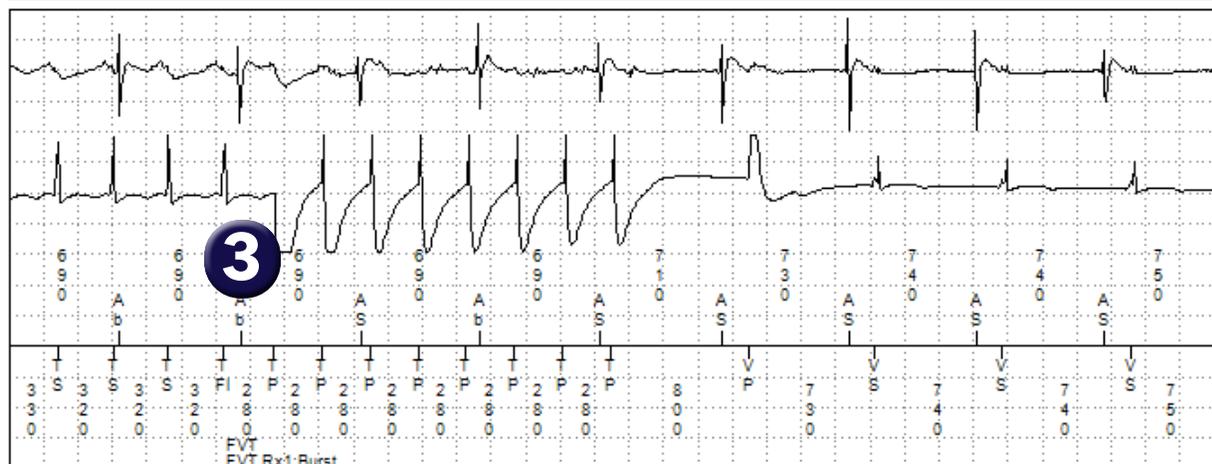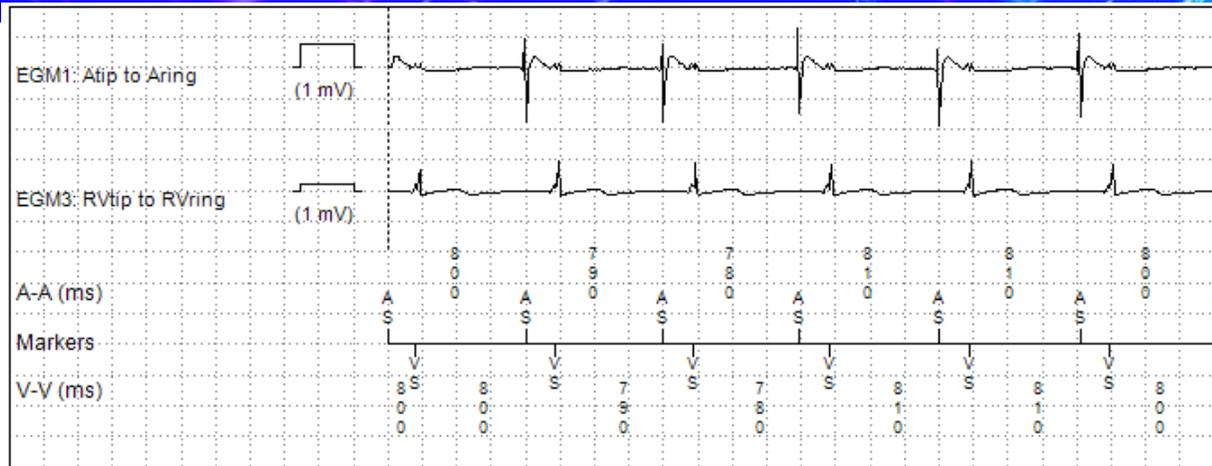
Episode #50: 04-Oct-2022 23:52:54

Episode Summary

Initial Type	FVT, via combined count (spontaneous)
Duration	12 s
A/V Max Rate	Unknown/188 bpm
V. Median	188 bpm (320 ms)
Activity at onset	Rest, Sensor = 61 bpm
Last Therapy	FVT Rx1: Burst, Successful

④

Initial VT/VF Detection Withheld By

None

Therapies	Delivered	Charge	Ohms	Energy
FVT Rx1 Burst	Seq 1			
|				
Termination				

Wavelet Measurements Prior to Initial VT/VF Detection

Wavelet Result: VT/VF

-8.	No Match	40 %
-7.	No Match	40 %
-6.	No Match	46 %
-5.	No Match	40 %
-4.	No Match	40 %
-3.	No Match	40 %
-2.	No Match	46 %
-1.	No Match	43 %
0.	Detection	

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	310 ms (194 bpm)
FVT	via VF			280 ms (214 bpm)
VT	On	100	12	360 ms (167 bpm)
Monitor	Monitor	110		400 ms (150 bpm)

PR Logic/Wavelet

AF/Afl	On
Sinus Tach	On
Other 1:1 SVTs	On
Wavelet	On, Match = 70 %
Template	29-Sep-2022, Auto = On
SVT V. Limit	260 ms

Other Enhancements

Stability	Off
Onset	Off
High Rate Timeout	
VF Zone Only	Off
All Zones	Off
TWave	On
RV Lead Noise	On

Polarity	**RV**
Pace Polarity	Bipolar
Sense Polarity	Bipolar

EGM	Source	Range		Sensitivity	
EGM1	Atip to Aring	+/- 8 mV		Atrial	0.3 mV
EGM3	RVtip to RVring	+/- 8 mV		RV	0.3 mV

3 What is your diagnosis?

The EGM shows a regular, monomorphic tachycardia, alternately detected in the VT zone and the FVT zone; the combined counter is full, with 35 cycles classified as TS or TF. (7/6 of 30 cycles); analysis of the last 8 cycles before diagnosis shows at least one cycle classified as TF leading to the diagnosis of FVT; the first therapy in the VF zone (a burst) is delivered with termination of the arrhythmia.

4 What is the diagnosis made by the system?

The diagnosis is that of FVT via the combined counter.

Key messages

- This plot shows another example of how the combined counter works.

- The tachycardia oscillates between the VT zone and the FVT zone programmed via VF; therefore the 2 VT and VF counters increment in parallel.

- The combined counter has been developed to avoid delaying therapy in this scenario.

- When the combined counter is filled (35 TS or TF cycles in this example), the device analyses the last 8 intervals; here, no cycle is classified as FS, but at least one of the cycles is classified as TF, leading to a diagnosis of FVT.

14 VT and the monitor zone

Patient

Male implanted with a single-chamber defibrillator (Evera XT VR) for primary prevention of severe dilated cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VT-Mon				1964	26-Feb-2022	16:38	:07:41	157	162	Rest
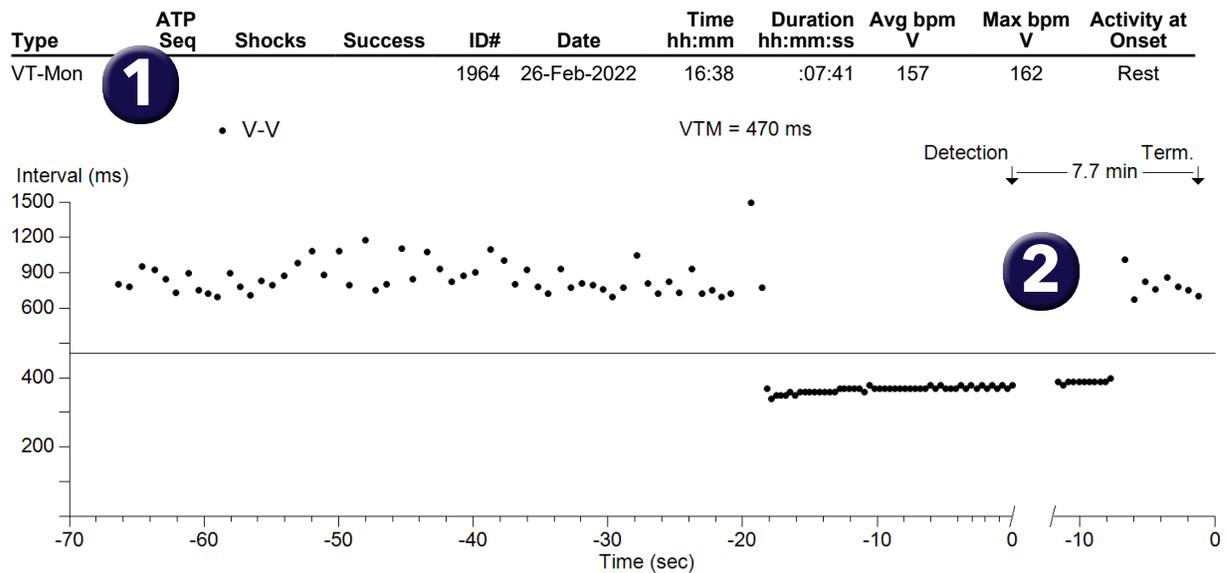
1 2 What diagnosis is suggested by the interval plot?

The episode was classified as VT-Mon by the device (1); the plot shows a regular tachycardia in the monitor zone, terminating spontaneously after more than 7 minutes (2).

EGM1: RVtip to RVring

(1 mV)

EGM2: Can to RVcoil

(1 mV)

Markers

V-V Interval (ms):

| V S | 7 4 0 | V S | 9 4 0 | V S | 7 3 0 | V S | 7 6 0 | V S | 7 0 0 | V S | 7 3 0 | V S |

| 1500 | | V P | | 7 8 0 | | V S | 3 7 0 | V S | 3 4 0 | V S | 3 5 0 | V S | 3 5 0 | V S | 3 6 0 | V S | 3 5 0 | V S | 3 6 0 | V S | 3 6 0 | V S | 3 6 0 | V S | 3 6 0 | V S | 3 6 0 |

| V S | 3 6 0 | V S | 3 7 0 | V S | 3 7 0 | V S | 3 7 0 | V S | 3 6 0 | V S | 3 8 0 | V S | 3 7 0 | V S | 3 7 0 | V S | 3 7 0 | V S | 3 7 0 | V S | 3 7 0 | V S | 3 7 0 | V S | 3 7 0 | V S | 3 7 0 | V S | 3 7 0 | V S |

❸

Waveform
for 7.

| 3 7 0 | V S | 3 8 0 | V S | 3 7 0 | V S | 3 8 0 | V S | 3 7 0 | V S | 3 7 0 | V S | 3 7 0 | V S | 3 8 0 | V S | 3 7 0 | V S | 3 8 0 | V S | 3 7 0 | V S | 3 8 0 | V S | 3 7 0 | V S | 3 8 0 | V S | 3 7 0 | V S | 3 8 0 | V T |

VTM

61
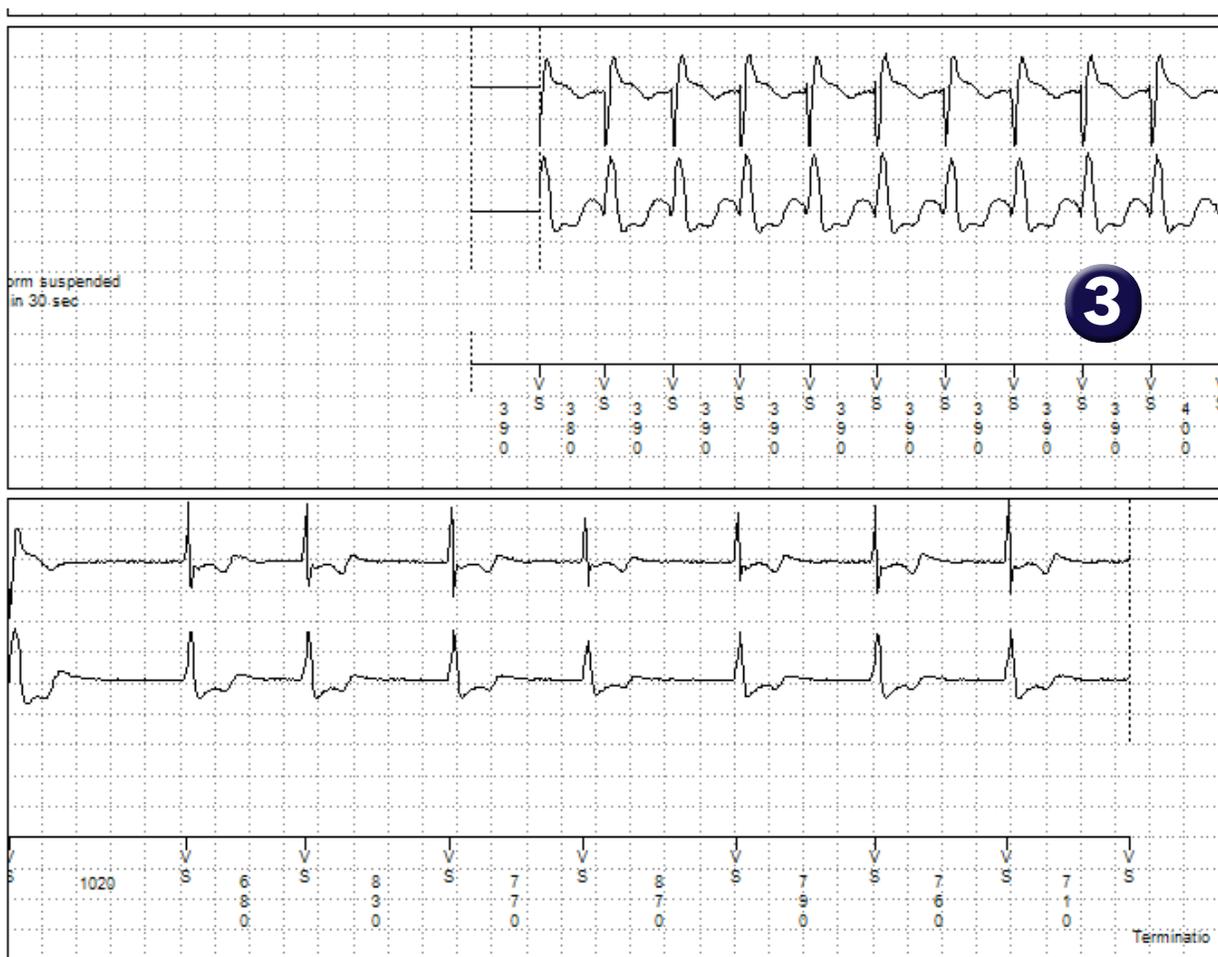
3 What is your diagnosis?

The EGM showed probable VT in the monitor zone (cycles classified as VS) with spontaneous reversion.

Key messages

- This trace shows a VT episode recorded in the monitor zone; in a monitor zone, no therapy is programmed.

- Latest international recommendations favour programming a single VF zone for primary prevention with rates > 188 bpm; the aim is to avoid inappropriate therapies and focus on treatment of the most serious, life-threatening arrhythmias.

- It may also be useful to programme a monitor zone to check for the occurence of slower arrhythmias that may warrant treatment.

Episode #1964: 26-Feb-2022 16:38:33

Episode Summary

Initial Type	VT Monitor (spontaneous)
Duration	7.7 min
V. Max Rate	162 bpm
V. Median	158 bpm (380 ms)
Activity at onset	Rest, Sensor = 40 bpm

Wavelet Measurements Prior to Initial VT Detection

Wavelet Result:	VT/VF	
Template Status:	OK	
-8.	No Match	64 %
-7.	No Match	61 %
-6.	No Match	58 %
-5.	No Match	61 %
-4.	No Match	61 %
-3.	No Match	61 %
-2.	No Match	61 %
-1.	No Match	58 %
0.	Detection	

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	290 ms (207 bpm)
FVT	via VF			250 ms (240 bpm)
VT	On	40	12	330 ms (182 bpm)
Monitor	Monitor	48		470 ms (128 bpm)

Wavelet

Wavelet	On, Match = 70%
Template	08-Jun-2015, Auto = On
SVT V. Limit	250 ms

Other Enhancements

Stability	40 ms
Onset	On (81%)
High Rate Timeout	
VF Zone Only	Off
All Zones	Off
TWave	On
RV Lead Noise	On

Polarity — **RV**

Pace Polarity	Bipolar
Sense Polarity	Bipolar

EGM	Source	Range	Sensitivity	
EGM1	RVtip to RVring	+/- 8 mV	RV	0.3 mV
EGM2 (Wavelet)	Can to RVcoil	+/- 12 mV		

950

AR

V V V V V V V V V V V
S S S S S S S S S S S

270 270 240 210 210 370 250 250 220 240 220

Therapies

1 a shock to restore a viable rhythm

Patient

Male implanted with a triple-chamber defibrillator (Claria Quad CRT-D) for severe dilated cardiomyopathy; hospitalised for loss of consciousness with a shock from the device.

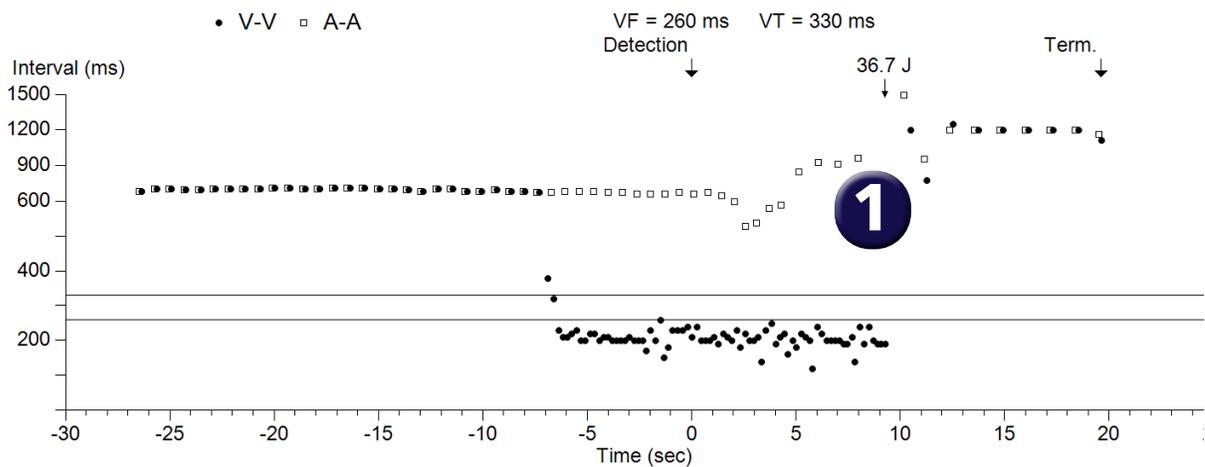| Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	0	35J	Yes	1	27-Feb-2019	11:16	:17	90/273	- - -/---	Active

1 What diagnosis is suggested by the interval plot?

The plot shows an episode compatible with a ventricular arrhythmia detected in the VF zone; the shock is delivered after 15 seconds and seems to terminate the arrhythmia.
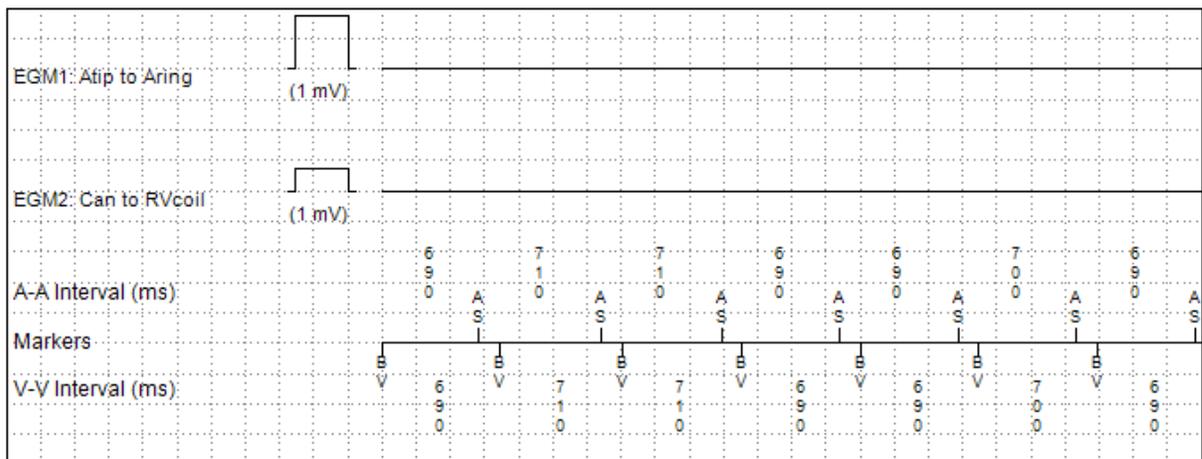
2 What is your final diagnosis?

The tracing shows a very rapid, polymorphic, ventricular arrhythmia (atrioventricular dissociation, ventricular rhythm faster than the atrial rhythm), detected in the VF zone; the initial VF counter is filled following 30 out of 40 cycles in the VF zone, triggering charging of the capacitors (VS markers); at the end of charging, there is confirmation of arrhythmia persistence (2 fast cycles out of 5) and the shock is delivered.

3 What is the effect of the shock?

The shock is effective and terminates the arrhythmia.

Key messages

- For Medtronic™ defibrillators, a maximum of 6 shocks can be delivered for a single episode in the VF zone.

- Although the output of each shock can be programmed independently, it is usual to program a maximum output shock (35 Joules) for shocks 2 to 6; on the other hand, the output of the first shock can either be programmed at the device's maximum output, at a value 10 Joules lower (25 Joules), or at a lower output tested during an induction procedure.

- Programming a medium-output first shock (between 15 and 20 Joules) reduces the charge time and the delay between the onset of arrhythmia and delivery of the shock, and may in certain specific cases, reduce the risk of loss of consciousness.

- The choice of output for the first shock in the VF zone therefore represents a compromise: medium output may be sufficient to stop VF after a short charge time, but if this fails, the second shock of maximum energy will be delivered following a longer duration in VF; high energy from the outset is more effective for VF, but at the cost of a longer initial charge time.

2 defibrillation threshold and upper limit of vulnerability

Patient

Patient with very severe ischaemic cardiomyopathy implanted with a triple chamber defibrillator (Viva XT CRT-D) hospitalised for prolonged loss of consciousness and according to witnesses, several shocks delivered by the device.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
FVT	1	5	Yes	995	26-Nov-2015	00:16	:01:07	38/222	---/286	Rest
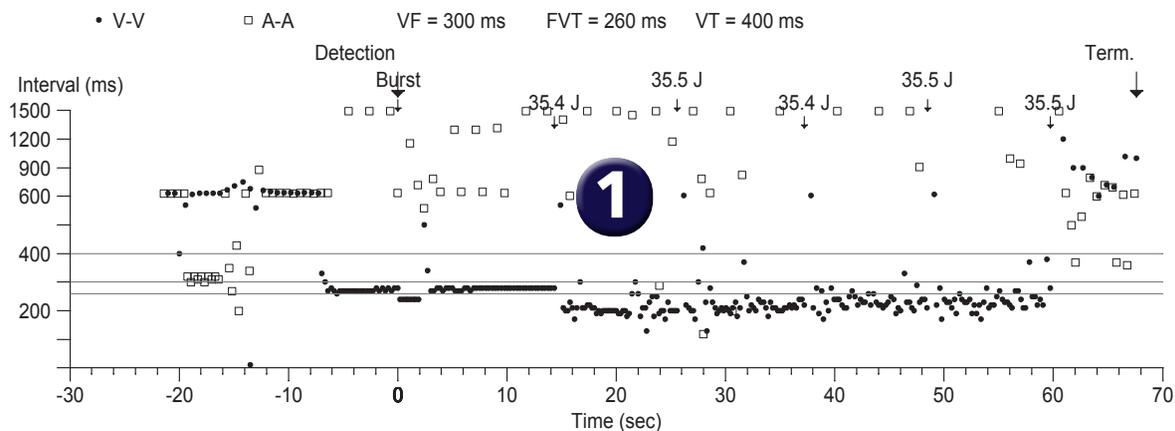
1 What diagnosis is suggested by the interval plot?

The plot shows a sudden acceleration of the ventricular rhythm in the FVT zone, followed by a sequence of anti-tachycardia pacing (ATP) which does not terminate the arrhythmia; a first shock is delivered, which does not revert the arrhythmia but instead causes it to accelerate and become more disorganised, with detection in the VF zone; the next 3shocks are ineffective; the fifth shock is effective, terminating the arrhythmia.

EGM1: Atip to Aring

(1 mV)

EGM3: RVtip to RVring

(1 mV)

A-A (ms):

Markers.

V-V (ms):

2

FVT

FVT
FVT Rx 2 CV
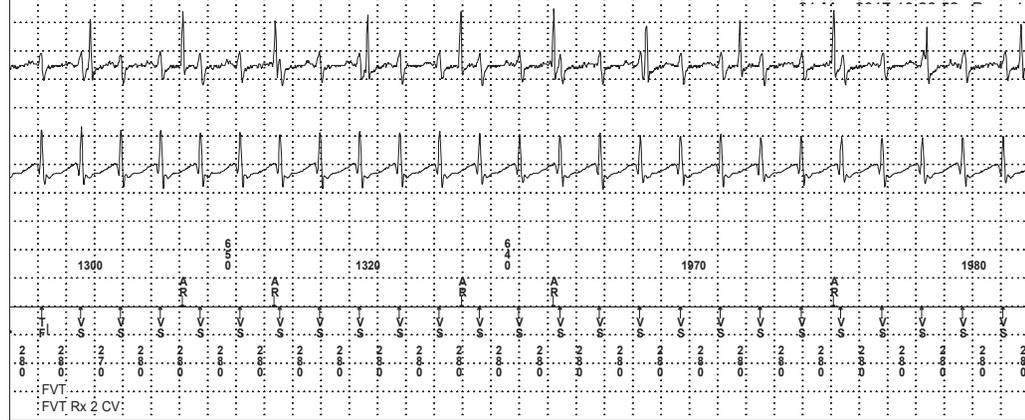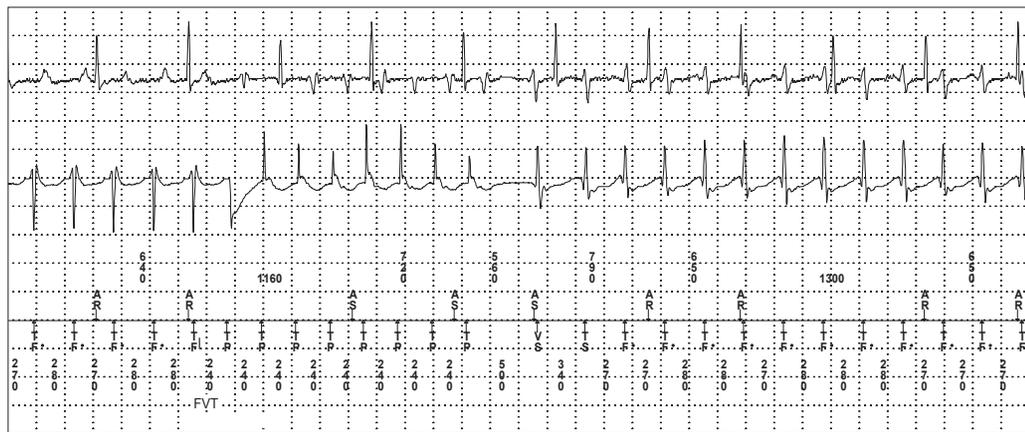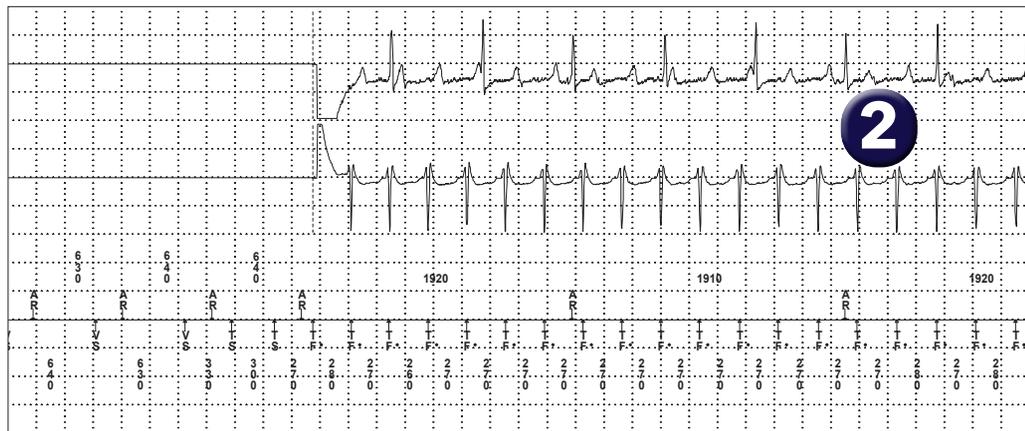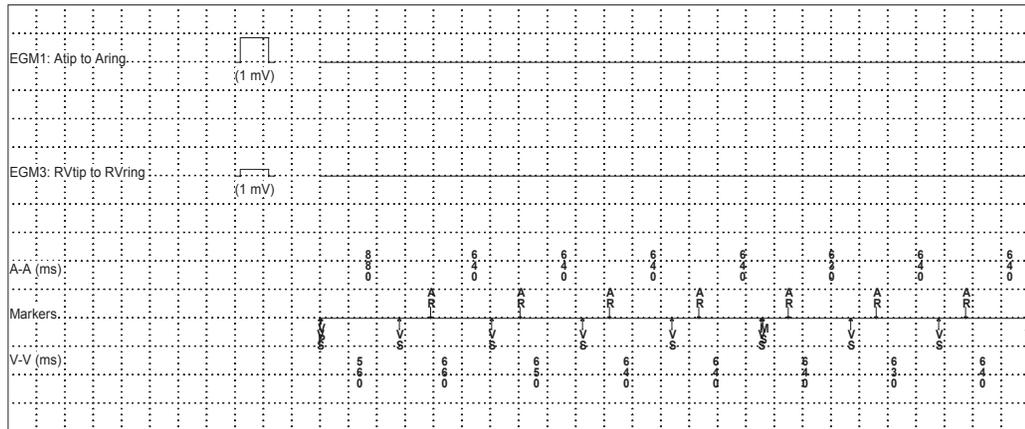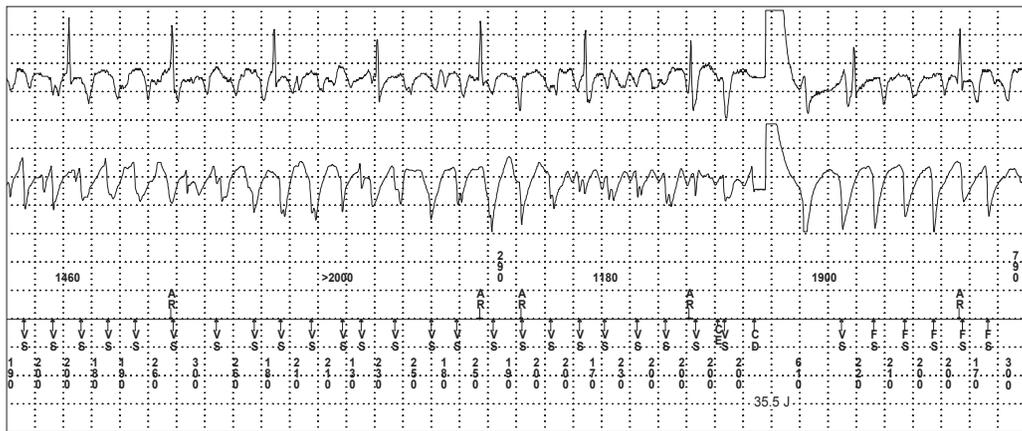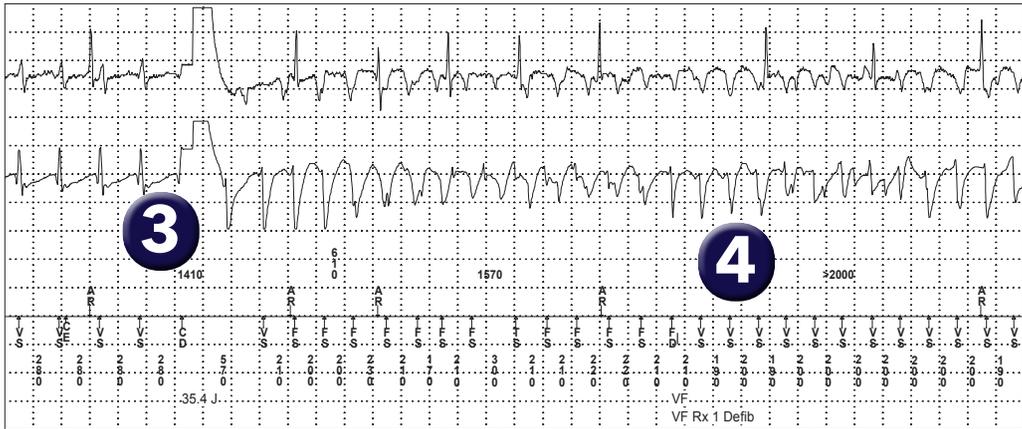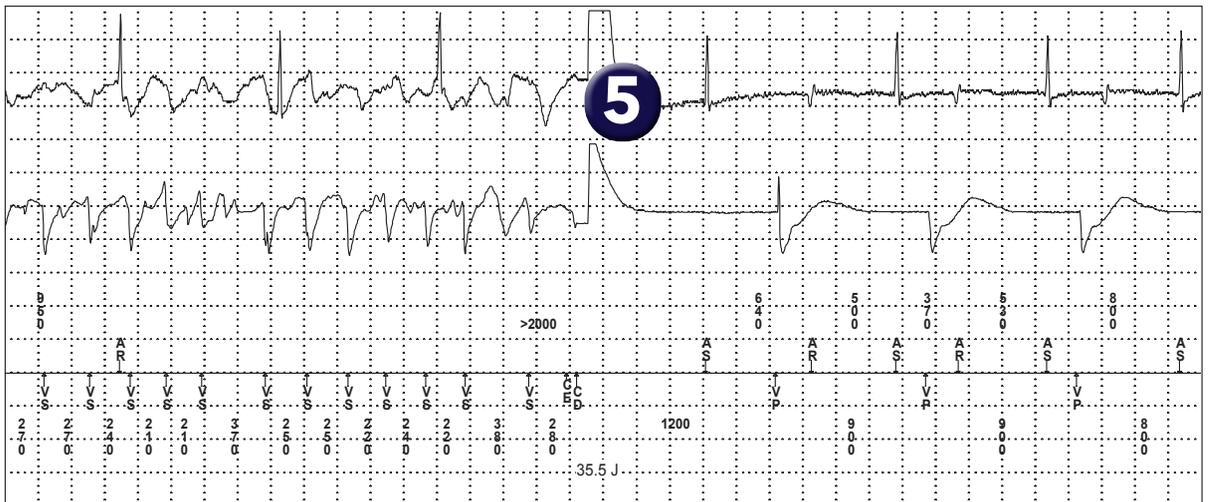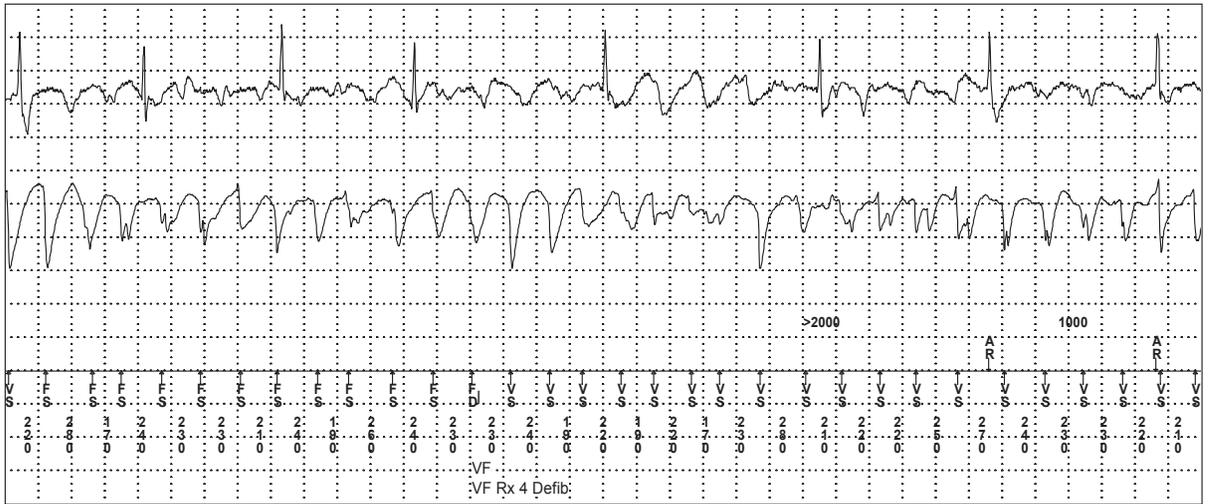
2 **What type of arrhythmia is this?**

It is a regular, monomorphic ventricular tachycardia (atrioventricular dissociation) detected in the FVT zone.

3 **Why is the shock delivered on the third rapid cycle after the end of charging?**

As this is the first shock of the episode, there is a confirmation phase at the end of charging; the shock is usually delivered on the second rapid ventricular cycle; in this example, the shock is synchronised to the third instead of the second cycle following the end of charging because this cycle falls within the vulnerable atrial period; this window, which lasts from 150 to 400 ms after a sensed atrial signal, was created to avoid inducing atrial fibrillation (ventricular shock delivered during the atrial vulnerable period).

4 **What is the effect of the first shock?**

Not only does the shock fail to terminate VT, it causes worsening of the arrhythmia, which becomes very rapid, polymorphic and irregular (VF).

5 **What is the effect of the following shocks?**

The next 3 shocks (shocks 2-4) are ineffective, the fifth is effective.

Key messages

- The arrhythmia episode in this patient is extremely worrying because it was only terminated by the fifth maximum output shock, the penultimate therapy available; in fact in Medtronic defibrillators, the maximum number of shocks for a single episode is limited to 6; the probability of a successful shock after 6 maximum unsuccessful attempts is low; conversely, it is preferable to limit the number of shocks if the therapies are inappropriate.

- This case illustrates one of the main problems encountered in patients implanted with a defibrillator: patients with a high defibrillation threshold are also those in whom an appropriate or inappropriate shock is most likely to induce a polymorphic ventricular arrhythmia that may compromise the patient's survival (with a significant risk that subsequent shocks may be ineffective…).

- There is a direct relationship between the amount of energy required to induce ventricular fibrillation and the energy required to terminate it (concept of upper limit of vulnerability); in this patient, the first shock degrades a monomorphic, organised arrhythmia into a polymorphic, chaotic arrhythmia, suggesting the existence of a high upper limit of vulnerability; the shock did not capture a sufficient quantity of ventricular myocardium, but instead created sufficiently pro-arrhythmogenic myocardial heterogeneity to generate multiple reentry circuits; it is therefore not surprising that the subsequent delivery of the same amount of energy does not terminate the VF episode induced by the first shock and that several shocks are necessary (high defibrillation threshold).

- Therefore this tracing highlights 2 important points: 1) a shock from the device usually terminates episodes of ventricular arrhythmia and is the basic treatment of the defibrillator; however, a shock can sometimes be pro-arrhythmogenic and, as in this patient, transform an organised VT into a potentially lethal VF; 2) the defibrillation threshold is not a fixed value; in this case, several shocks at maximum energy were ineffective whereas the fifth shock of equal energy averted a dangerous situation.

- This patient's safety was compromised with few reprogramming options available; a coil positioned in the coronary sinus was added; a shock delivered between two coils in contact with, or in the immediate vicinity of the myocardium is more likely to be effective by extending the electric field induced over a larger volume of myocardium.

3 anti-tachycardia pacing in the VF zone

Patient

Male implanted with a triple chamber defibrillator (Viva Quad CRT-D) for ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	1		Yes	5	01-Mar-2016	15:33	:12	95/231	- - -/---	Rest
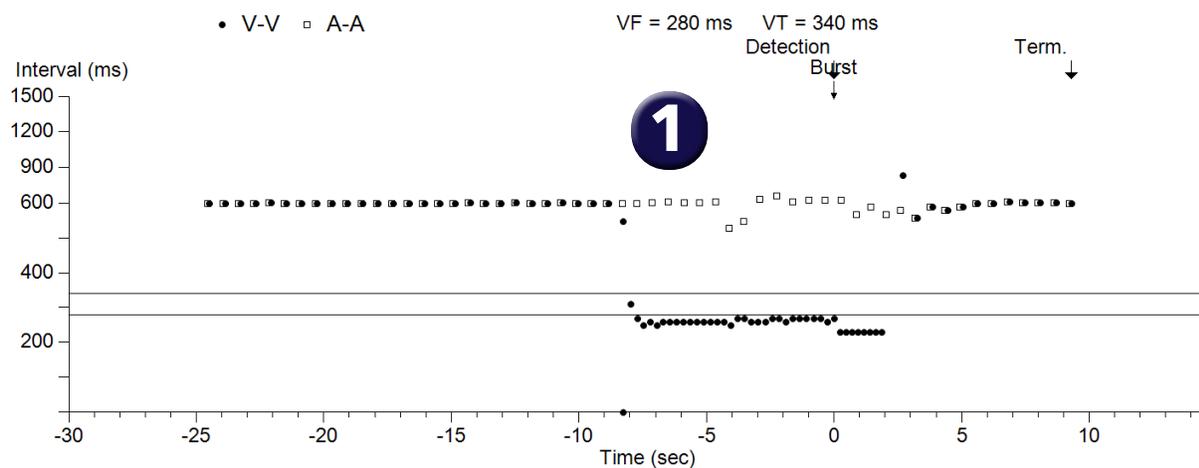
1 What diagnosis is suggested by the interval plot?

Probable episode of monomorphic VT detected in the VF zone and treated by a burst which appears to be effective

Aborted
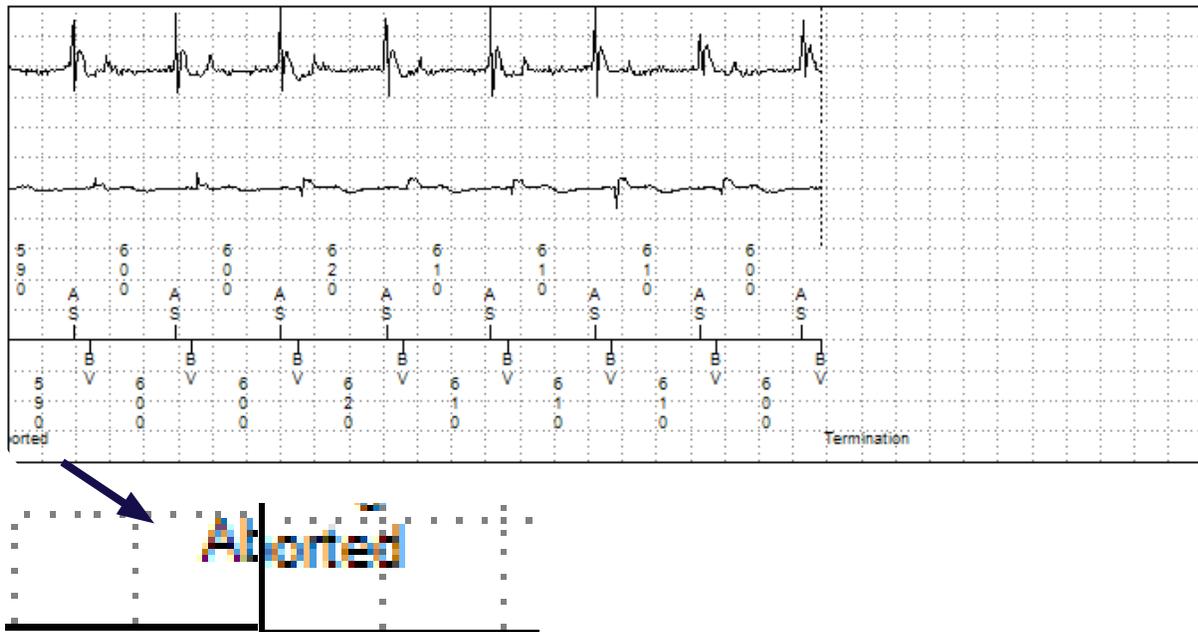
2 What therapy is delivered by the device?

The episode is detected in the VF zone; when the initial VF counter is filled, a burst during charging is delivered.

3 What does the «abandon» message mean?

Charging of capacitors began as soon as the VF counter was filled; the burst was effective with termination of the arrhythmia; after 4 consecutive paced ventricular cycles, the criterion for confirming persistence of the arrhythmia is not met (criterion of 2/5 rapid cycles) and charging is interrupted (therapy abandoned).

Key messages

- Various studies have shown that a significant proportion of rapid ventricular arrhythmias (cycle length < 320 ms) classified in the VF zone are regular and monomorphic.

- Although it is clear that delivering a shock during an episode of ventricular fibrillation is the only therapy likely to re-establish a viable rhythm, programming should be optimized to minimise number of shocks delivered (inappropriate or appropriate but avoidable) as much as possible.

- A shock delivered to a conscious patient is painful and significantly increases battery consumption; a series of shocks to the same patient is associated with a risk of premature battery depletion and a significant deterioration in quality of life (numerous cases of depression or anxiety induced by a series of shocks have been described).

- An endocardial shock is accompanied by microscopic myocardial lesions, an increase in cardiac enzymes (troponin, CK, myoglobin) and macroscopic lesions that are all the more significant with higher energy delivery (momentary drop in left ventricular ejection fraction and cardiac output, particularly in patients with already impaired contractility).

- The PainFree Rx study (prospective, randomised, multi-centre study) showed that a single ATP sequence (8 beats at 88%) terminated a significant proportion of rapid tachycardias in the VF zone and significantly improved quality of life, by reducing the number of shocks delivered without increasing the risk of sudden death, syncope or accelerated tachycardia. Therefore, delivering an ATP sequence in the VF zone is often effective, painless, reduces battery consumption and improves quality of life.

- It is now recommended that at least one ATP sequence is programmed as first-line treatment for tachycardias up to 230 beats/minute, with bursts favoured over ramps (at least 8 stimuli with 88% coupling).

4 anti-tachycardia pacing in the VF zone and conserving energy

Patient

Same patient as the previous trace.

| Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	1		Yes	577	14-Mar-2016	04:25	:10	88/250	- - -/250	Rest
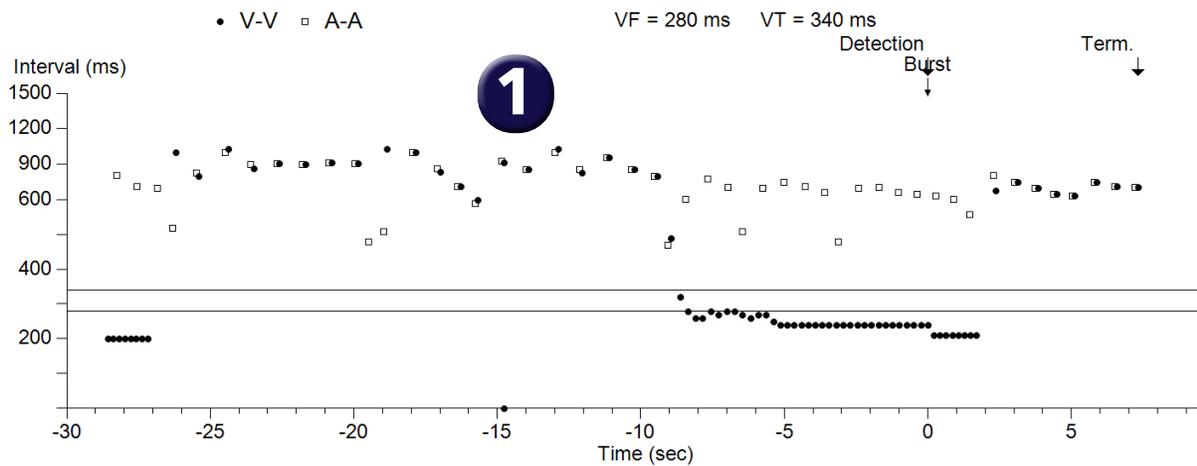
1 What diagnosis are you suggesting on this graph?

Probable episode of monomorphic VT detected in the VF zone and treated by a burst which appears to be effective.
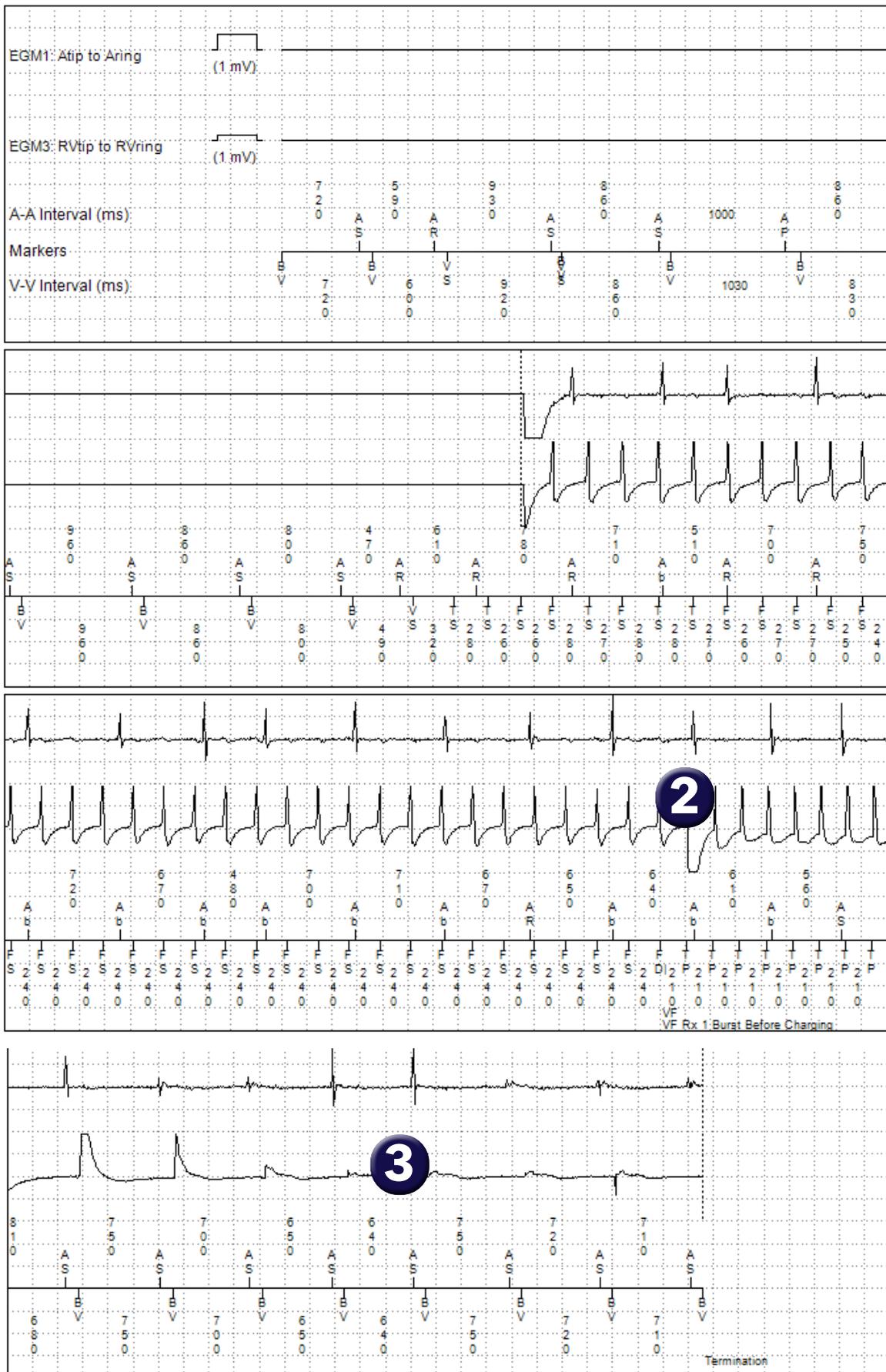
② What therapy is delivered by the device?

The episode is detected in the VF zone; when the initial VF counter is full, a burst before charging is delivered.

③ Has the device charged its capacitors?

No, this is a burst before charging; when the burst is effective, the device does not charge its capacitors.

Key messages

- 2 options are available in the VF zone: ATP during charging or ATP before charging.

- ATP during charging enables ventricular tachycardias to be treated painlessly without the risk of delaying shock therapy; once the diagnosis of VF has been established, charging begins and ATP is delivered simultaneously; if VF is re-confirmed after ATP, the shock is delivered ; if the patient has returned to sinus rhythm, the shock is not delivered; this makes it possible to treat the tachycardia painlessly if ATP is effective, without delaying the onset of the shock if the ATP is ineffective; on the other hand, even if ATP is effective, there is virtually no energy saved.

- ATP before charging reduces energy consumption; once VF has been diagnosed, ATP is delivered; if VF is reconfirmed after ATP has occurred, capacitors begin charging; if the arrhythmia is terminated, charging is not initiated; therefore this saves capacitor charging if ATP is effective; on the other hand, if ATP is ineffective, it delays the shock delivery by a few seconds.

- The device only delivers ATP before or during charging if the last 8 ventricular cycles detected are equal to or longer than the programmed value («deliver ATP if the last 8 RR intervals are ≥»); if charge saver is programmed, the device automatically switches from ATP during charging to ATP before charging if the former has been effective over a programmable number of consecutive episodes.

5 double anti-tachycardia pacing sequence

Patient

Same patient as above.
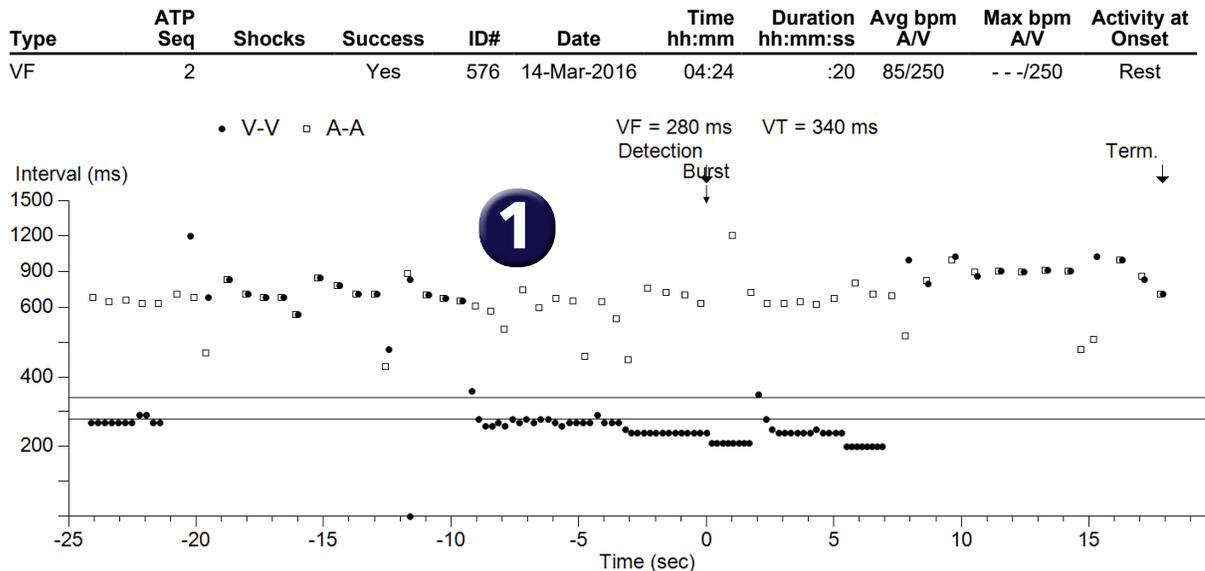
Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	2		Yes	576	14-Mar-2016	04:24	:20	85/250	- - -/250	Rest

1 What diagnosis is suggested by the interval plot?

Probable episode of monomorphic VT detected in the VF zone and treated by a first burst which appeared ineffective and then by a second burst which appeared effective.

2 What is the first therapy delivered by the device?

The episode is detected in the VF zone; when the initial VF counter is full, a burst before charging is delivered.

3 Has the device charged its capacitors?

No, this is a burst before charging; when the burst is effective, the device does not charge its capacitors.

EGM1: Atip to Aring
(1 mV)

EGM3: RVtip to RVring
(1 mV)

A-A Interval (ms):

Markers

V-V Interval (ms):

VF Rx 1 Burst Before Charging

VF Rx 1 Burst During Charging

VF Rx 1 Defib
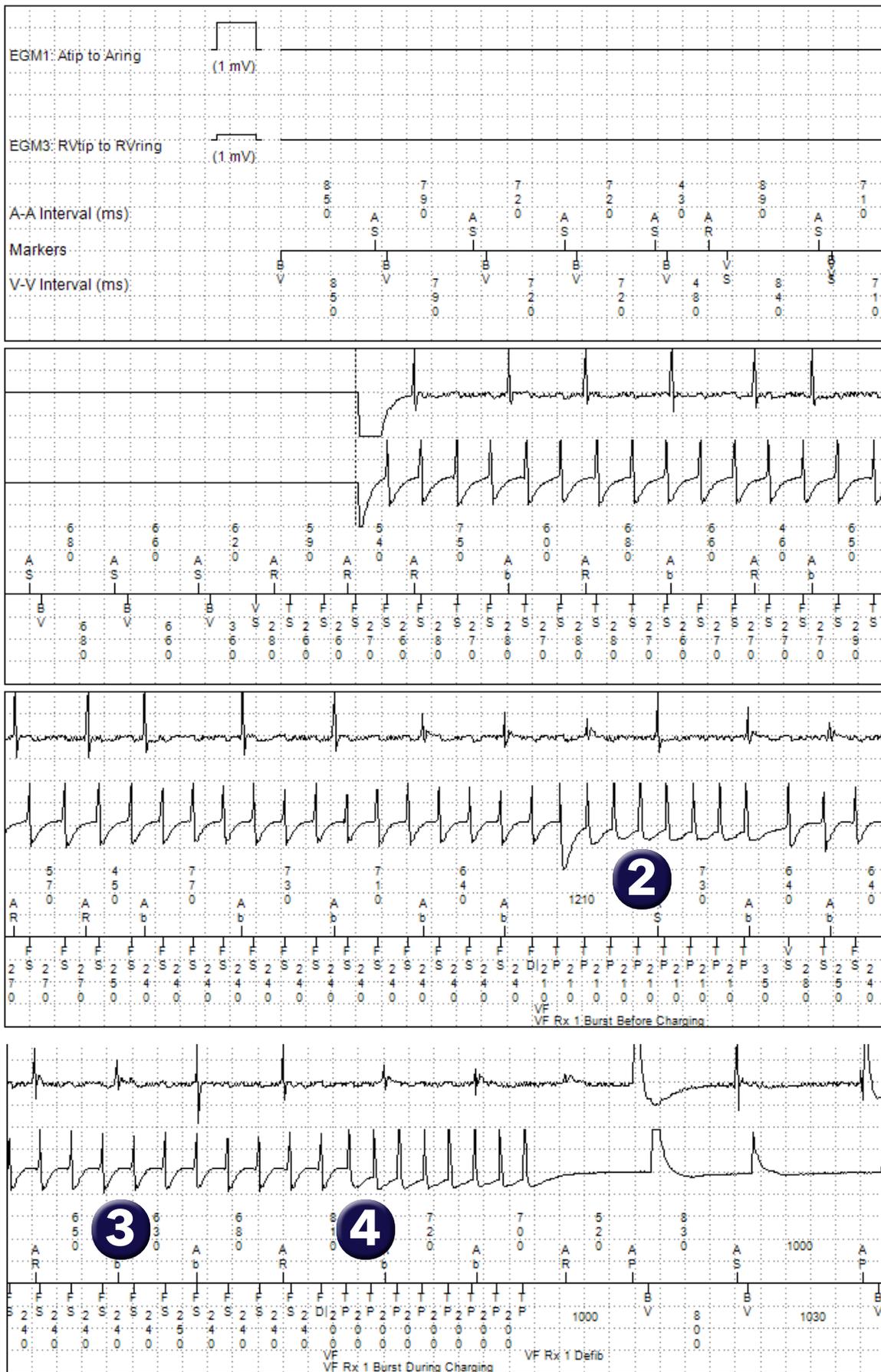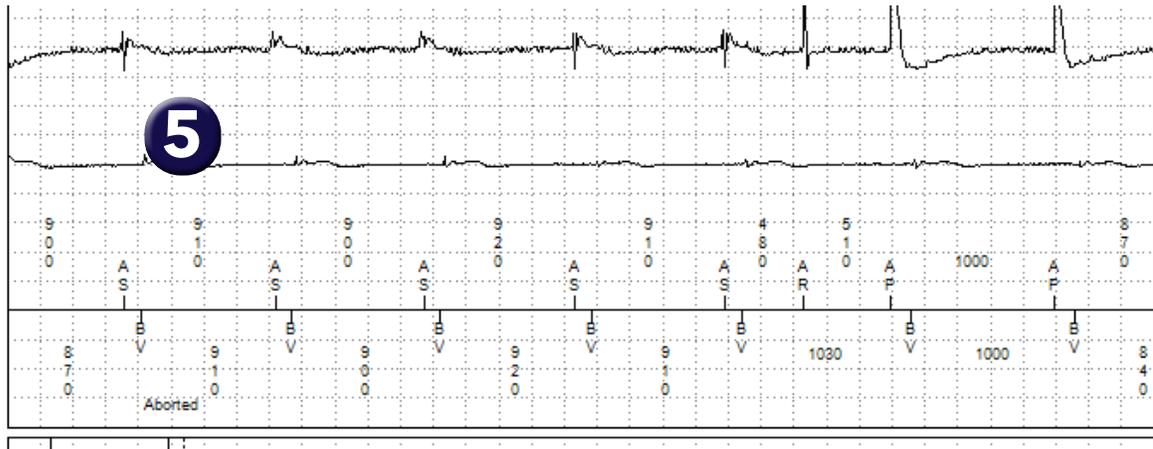
④ What is the second therapy delivered by the device?

The first burst was ineffective; the redetection criterion is verified (12 / 16 cycles classified as VF); the second therapy is a burst during charging (ATP + start of capacitor charging).

⑤ What does 'abandon' mean?

The burst was effective in terminating the arrhythmia; after 4 consecutive ventricular paced cycles, the criterion for confirming the persistence of the arrhythmia is not met (criterion of 2/5 rapid cycles) and the charge is interrupted (therapy discontinued).

Key messages

- This tracing shows a specific aspect of Medtronic defibrillators: the possibility of programming 2 bursts of ATP in the VF zone for the same episode.

- When ATP before charging is programmed, a first burst is delivered; if this burst proves ineffective, a burst during charging is delivered where the second burst and charging occur simultaneously; this helps increase the proportion of arrhythmias detected in the VF zone that are terminated by pacing rather than a shock.

6 anti-tachycardia pacing in the VT zone

Patient

Male implanted with a single chamber defibrillator (Visia XT VR) for ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VT	1		Yes	10	12-Aug-2021	01:59	:18	188	188	Rest
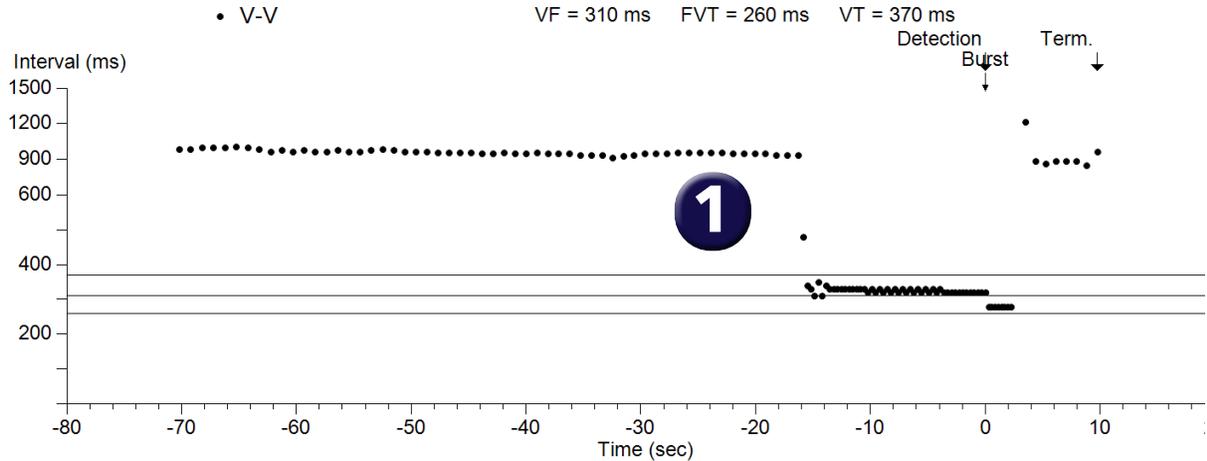
1 What diagnosis is suggested by the interval plot?

The plot shows a probable arrhythmic episode with sudden acceleration into the VT zone; a burst is delivered with probable termination of the arrhythmia; the plot on this single-chamber defibrillator does not allow us to differentiate with certainty between ventricular tachycardia and supra-ventricular tachycardia.

EGM1: RVtip to RVring
(1 mV)

EGM2: Can to RVcoil
(1 mV)

Markers

V-V Interval (ms):

	9 4 0		9 4 0		S	4 8 0	S	3 4 0	S	3 3 0	S	3 1 0	S	3 5 0	S	3 1 0	S	3 4 0	S	3 3 0	S

| S | 3 3 0 | S | 3 3 0 | S | 3 3 0 | S | 3 3 0 | S | 3 3 0 | S | 3 3 0 | S | 3 3 0 | S | 3 2 0 | S | 3 3 0 | S | 3 2 0 | S | 3 3 0 | S | 3 2 0 | S | 3 3 0 | S | 3 2 0 | S | 3 3 0 | S | 3 2 0 | S |

| S | 3 2 0 | S | 3 3 0 | S | 3 2 0 | S | 3 3 0 | S | 3 2 0 | S | 3 3 0 | S | 3 2 0 | S | 3 2 0 | S | 3 2 0 | S | 3 2 0 | S | 3 2 0 | S | 3 2 0 | S | 3 2 0 | S | 3 2 0 | S | 3 2 0 | S | 3 2 0 | S | 3 | DI 2 8 0 | P | 2 8 0 | P | 2 8 0 | P |

VT
VT Rx 1 Burst

| 2 8 0 | P | 2 8 0 | P | 2 8 0 | P | 2 8 0 | P | 2 8 0 | P | | 1220 | | V S | 8 9 0 | S | 8 7 0 | V S | 8 9 0 | S | 8 9 0 | V S | 8 9 0 |

❷ What is your final diagnosis?

This is a regular, monomorphic tachycardia with QRS complexes that appear wide on the shock channel; the burst is effective with termination of the arrhythmia; the morphology of QRS complexes post-termination is different from the morphology during tachycardia; therefore the diagnosis of ventricular tachycardia is very likely.

Key messages

- A priority during programming is to reduce the number of shocks delivered without compromising patient safety; ideally, this is achieved by interrupting the tachycardia with the least aggressive and least painful therapy possible; for organised tachycardias, ATP is preferred over a shock as first-line therapy since it is less painful and limits battery consumption; moreover, potentially deleterious effects of device based shocks have been clearly demonstrated.

- The principle underlying ATP is the existence of an excitable gap in a reentrant circuit such that rapid pacing can generate a new activation front that collides with the tachycardia circuit and interrupts it; the ventricle must therefore be paced at a higher rate than that of the tachycardia.

- The efficacy of this type of therapy has been demonstrated for a wide range of ventricular tachycardia with rates of up to 240 beats/minute; one or more ATP sequences can terminate up to 90% of ventricular tachycardias of less than 200 beats/minute, with a moderate risk of acceleration of approximately 1 to 5%.

- These observations have redefined the role of the implantable cardiac defibrillator as a device that offers ATP as a first line treatment, and possible defibrillation as a back-up.

- One or more ATP sequences can be programmed empirically without the need to test efficacy with an electrophysiology study.

7 bursts or ramps ?

Patient

Male implanted with a single chamber defibrillator (Visia XT VR) for ischaemic cardiomyopathy.(same patient as above).

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VT	4		Yes	9	12-Aug-2021	01:33	:38	188	188	Rest

1 What diagnosis is suggested by the interval plot?

The plot shows a probable arrhythmic episode identical to the previous trace with sudden acceleration into the VT zone; 3 bursts prove ineffective, a ramp interrupts the arrhythmia.

2 What is your final diagnosis?

The tachycardia is identical to the previous tracing; the first 3 bursts (fixed rate) are ineffective; the first ramp (increasing rate) allows termination.

Key messages

- In a burst, the cycle length is constant throughout the sequence (no change in rate from one stimulus to the next); this is the type of sequence most commonly used in clinical practice and probably the least aggressive; according to the latest recommendations, a burst should be preferred over other pacing sequences.

- In a ramp, the cycle length is reduced from one stimulus to the next by the value of the programmable decrement.

- In a ramp+ (specific to this manufacturer), the cycle length decreases for the first 3 intervals and then remains constant thereafter.

- The shorter the coupling intervals, the more aggressive the therapy and the greater the risk of accelerating the tachycardia; according to the latest recommendations, for a burst, a coupling interval of 88% of the cycle length of the tachycardia (calculated over the last 4 cycles before diagnosis) should be programmed. Ramps should be programmed at long coupling intervals (88-90%) and a limited number of pulses so as not to stimulate too aggressively. Medtronic devices add an impulse for each ramp sequence (so ramps become increasingly aggressive).

- Smart Mode can be programmed to deactivate a therapy when it has proved ineffective; this algorithm deactivates an ATP pacing sequence that has been ineffective for 4 consecutive episodes (variable depending on the platform).

- An additional option is the programming of the progressive therapy algorithm, which ensures that each therapy delivered for the same episode is at least as aggressive as the previous therapy.

- This patient presented with numerous episodes of VT effectively treated by ATP; rapid and effective treatment by ATP enabled the patient to remain asymptomatic with a good quality of life while preserving battery longevity.

8 acceleration after several sequences of anti-tachycardia pacing

Patient

Male implanted with a single-chamber defibrillator (Visia XT VR) for ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VT	6	35J	Yes	46	24-Jul-2021	01:33	:01:11	154	188	Rest
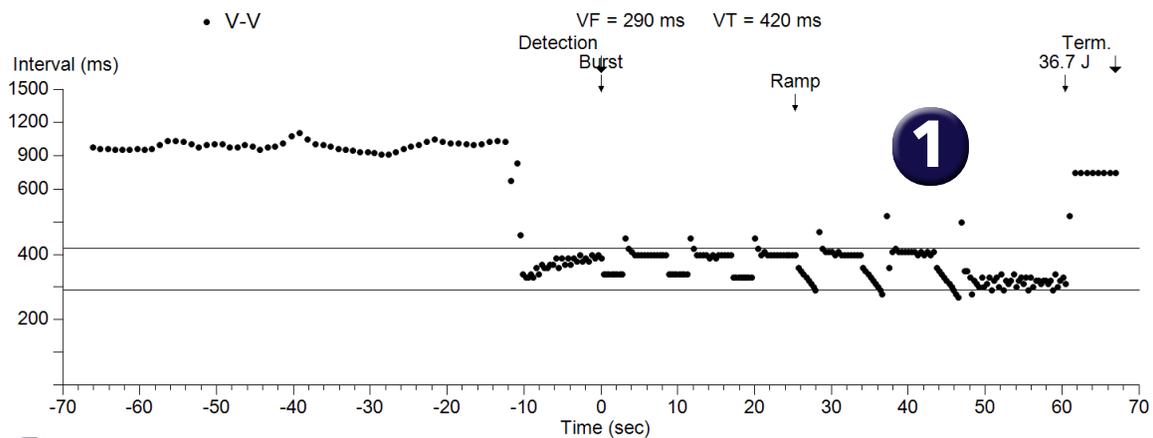
1 What diagnosis is suggested by the interval plot?

The plot shows a probable arrhythmic episode with sudden acceleration into the VT zone; the first 3 bursts and the first 2 ramps do not terminate the arrhythmia; the third ramp accelerates the arrhythmia which remains in the VT zone; a maximum output shock terminates the arrhythmia.
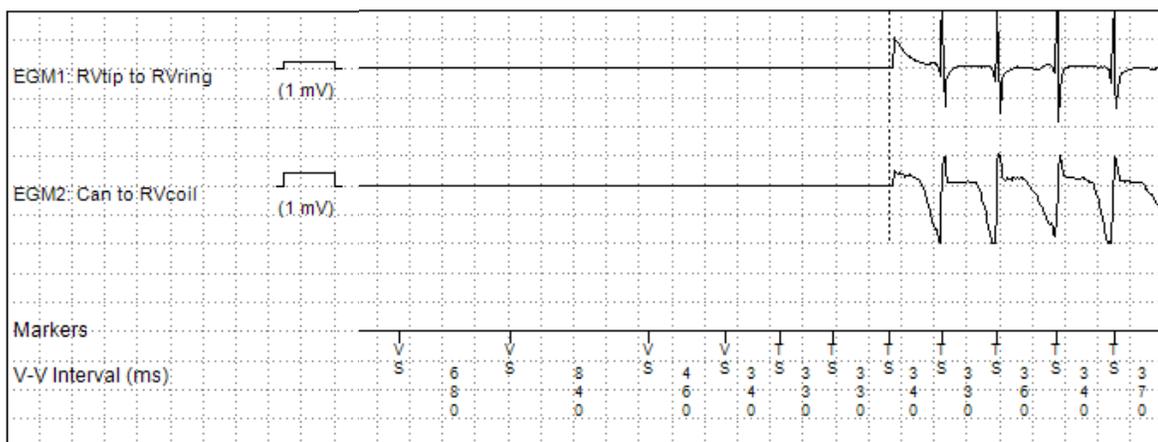
Termination
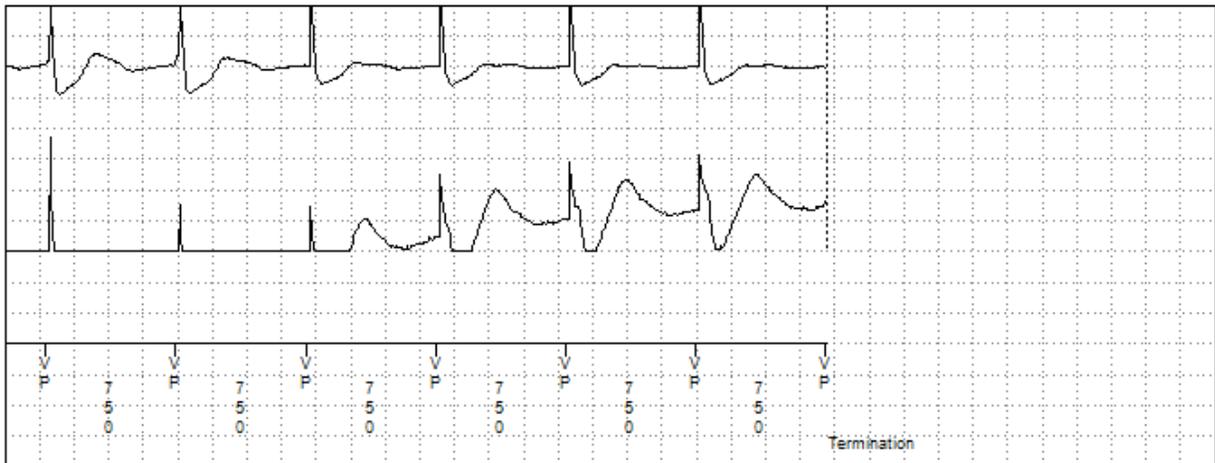
2 What is your final diagnosis?

This is a regular, monomorphic tachycardia with wide QRS complexes on the shock channel compatible with VT; the first 3 bursts (treatment 1) and the first 2 ramps (treatment 2) are ineffective; the third ramp accelerates the arrhythmia without significantly changing the morphology; a shock (treatment 3) terminates the arrhythmia.

Key messages

- Programming ramps after bursts is not systematically undertaken for this heart rate range, because this more aggressive therapy is associated with an increased risk of tachycardia acceleration, as in this example.

- Acceleration of VT and degradation into VF or rapid VT are well described complications following ATP with an incidence of around 1 to 5%; the efficacy and safety of ATP are inversely related; a greater number of tachycardias can be reverted with a more aggressive protocol (short coupling intervals, more cycles per sequence, more sequences) but with an increased risk of acceleration.

- There are 3 reasons why a shock may be delivered following the detection of an arrhythmia in the VT zone: 1) the shock is the first therapy programmed in the VT zone; 2) previous therapies (ATP) have proved ineffective; 3) an ATP sequence accelerates the tachycardia into the VF zone.

9 accceleration after anti-tachycardia pacing

Patient

Male implanted with a dual chamber defibrillator (Evera XT DR) for ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
FVT	1	35J	Yes	42	24-Oct-2022	21:33	:24	81/222	- - -/300	Rest
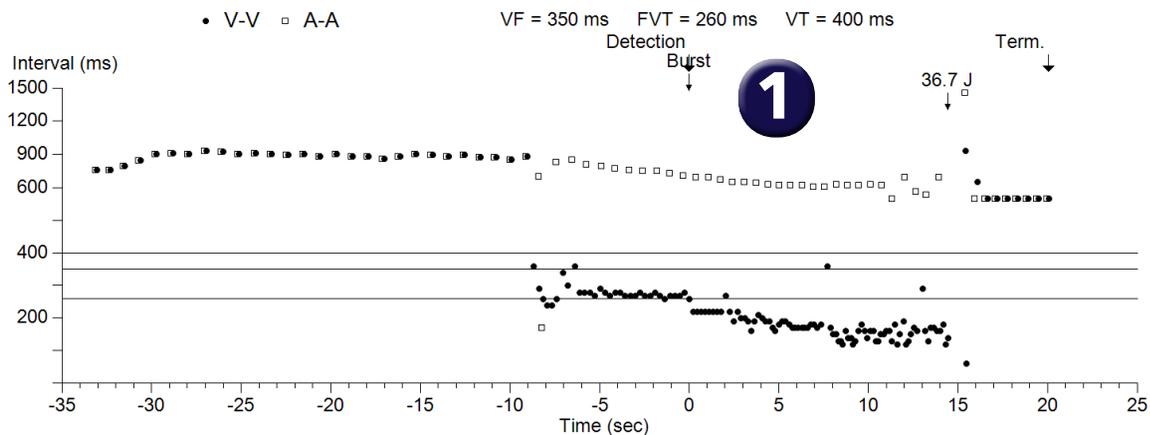
1 What diagnosis are you suggesting on this graph?

The plot shows a probable arrhythmic episode with sudden acceleration into the FVT zone (atrioventricular dissociation); the first burst accelerates the arrhythmia which becomes irregular and is detected in the VF zone; a maximum output shock facilitates reversion.
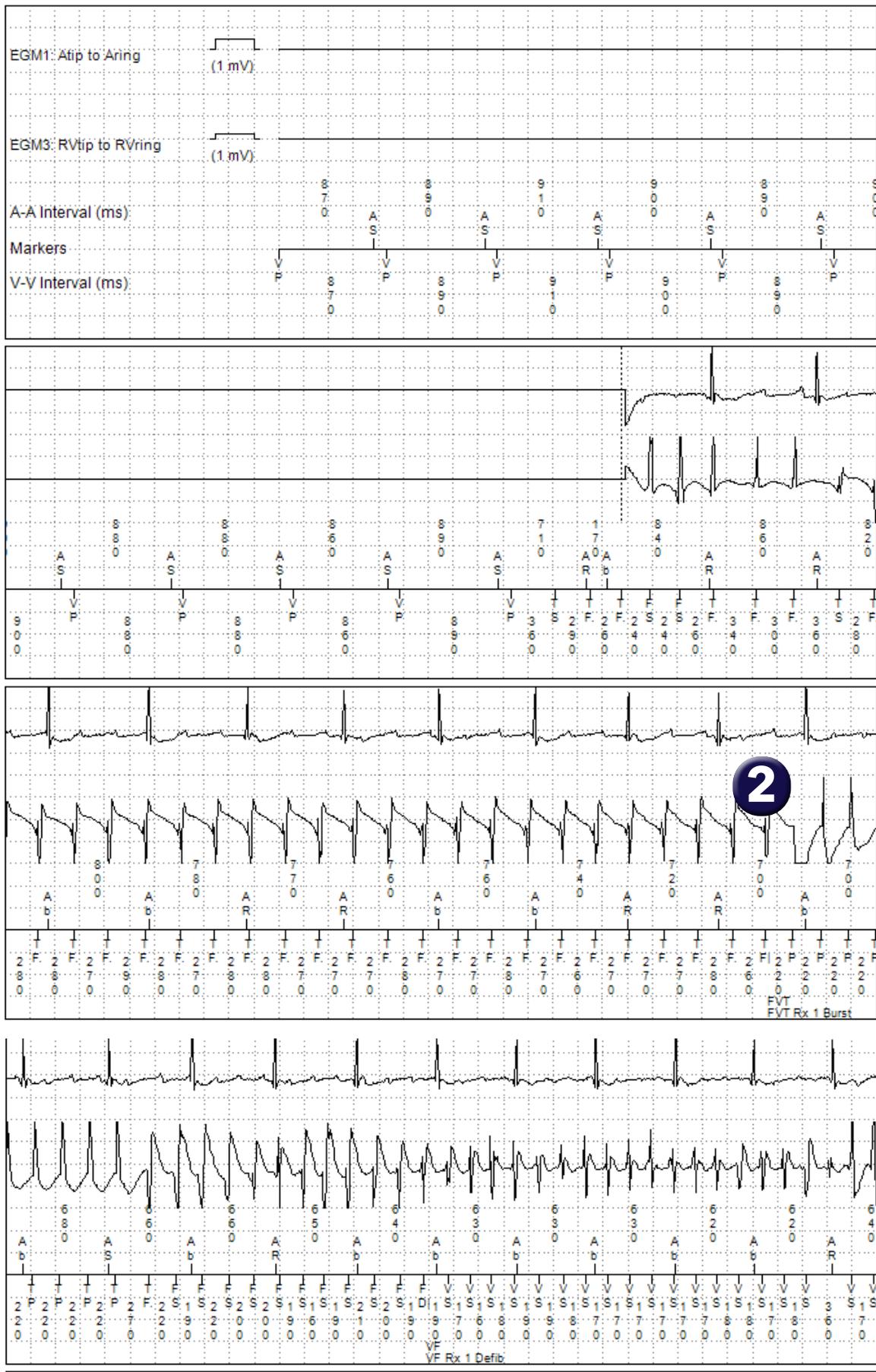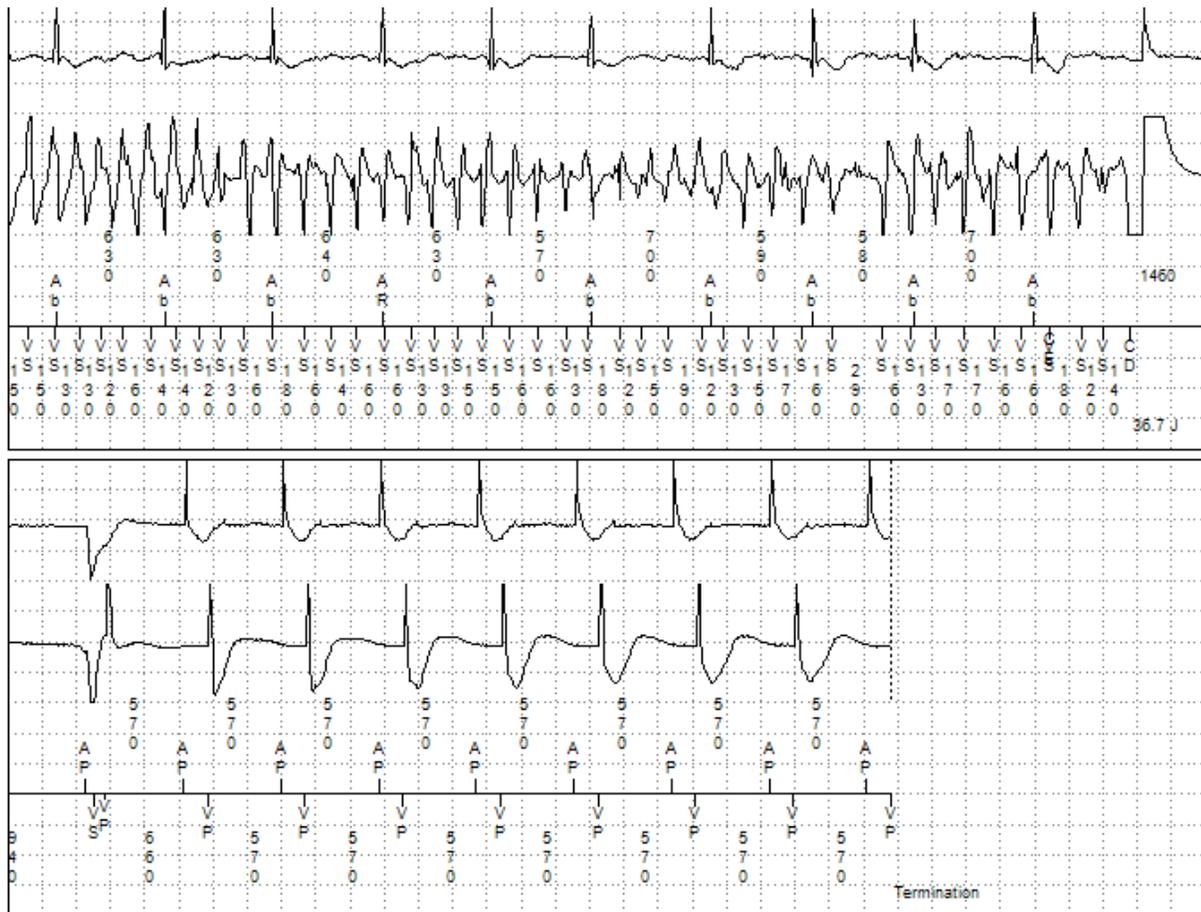
② What is your final diagnosis?

This is initially an episode of regular, monomorphic ventricular tachycardia; the first burst degrades the arrhythmia into ventricular fibrillation with extremely short cycles; a shock (first therapy in the VF zone) terminates the arrhythmia.

Key messages

- This tracing also shows an example of acceleration following an ATP sequence and serves to emphasise the often polymorphic and very rapid nature of induced arrhythmias.

- ATP can 1) accelerate a tachycardia resulting in a morphology identical to the previous one, 2) accelerate a tachycardia resulting in a different morphology or 3) cause an organised tachycardia to degenerate into VF.

10 pro-arrhythmogenic effect of a low output shock

Patient

Male implanted with a triple chamber defibrillator (Protecta XT CRT-D) for dilated cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VT	6	10J,35J	Yes	3	13-Jul-2015	16:03	:01:12	136/188	140/400	Active
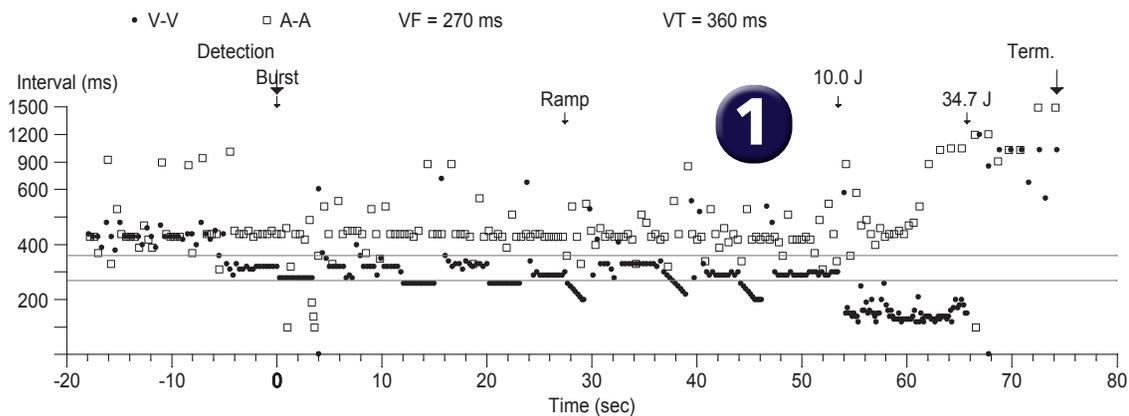
1 What diagnosis is suggested by the interval plot?

The plot shows an episode of ventricular arrhythmia with acceleration into the VT zone; the first 3 bursts and the first 3 ramps do not terminate the arrhythmia; a low output shock (10 Joules) accelerates the arrhythmia into the VF zone; a maximum output shock terminates the arrhythmia.

TV
TV Tt 1 Burst

TV
TV Tt 1/Séq 2

TV
TV Tt 1/Séq 3

TV
TV Tt 2 Ramp

TV
TV Tt 2/Séq 2

TV
TV Tt 2/Séq 3

TV
TV Tt 3 CV

10.0 J

FV
FV Tt 1 Défib
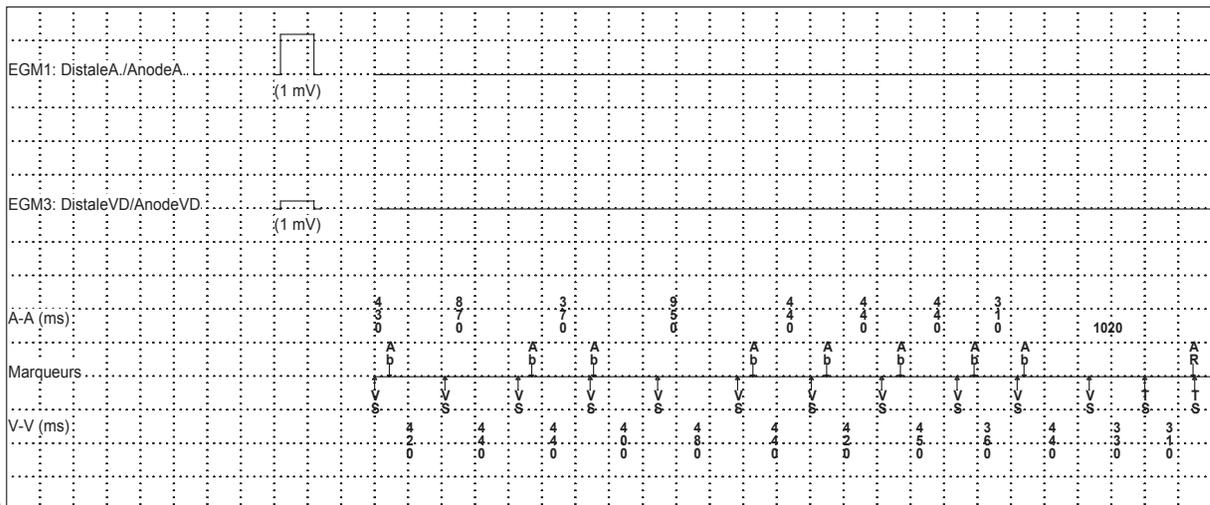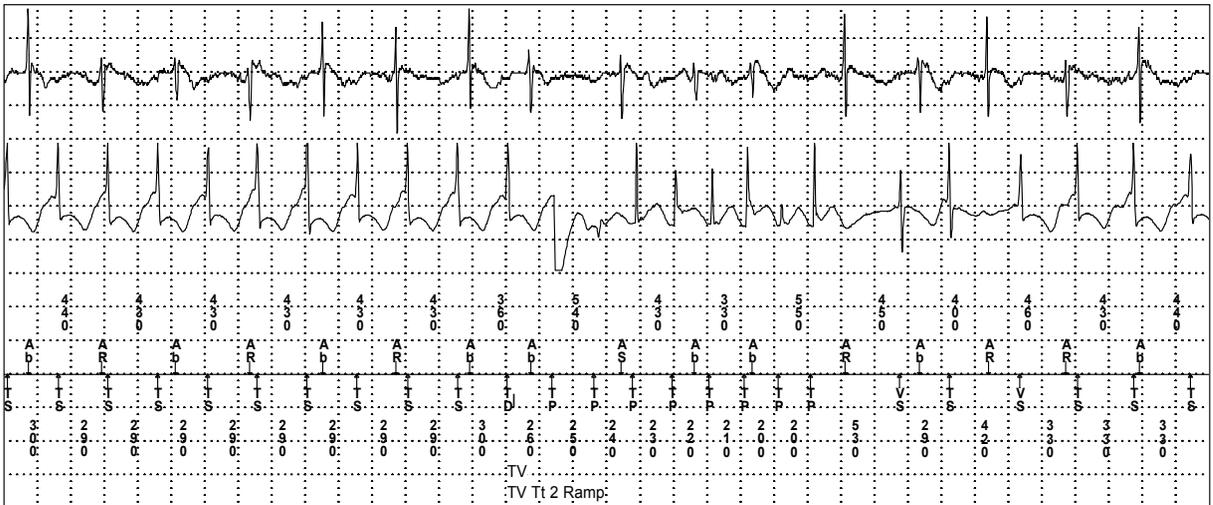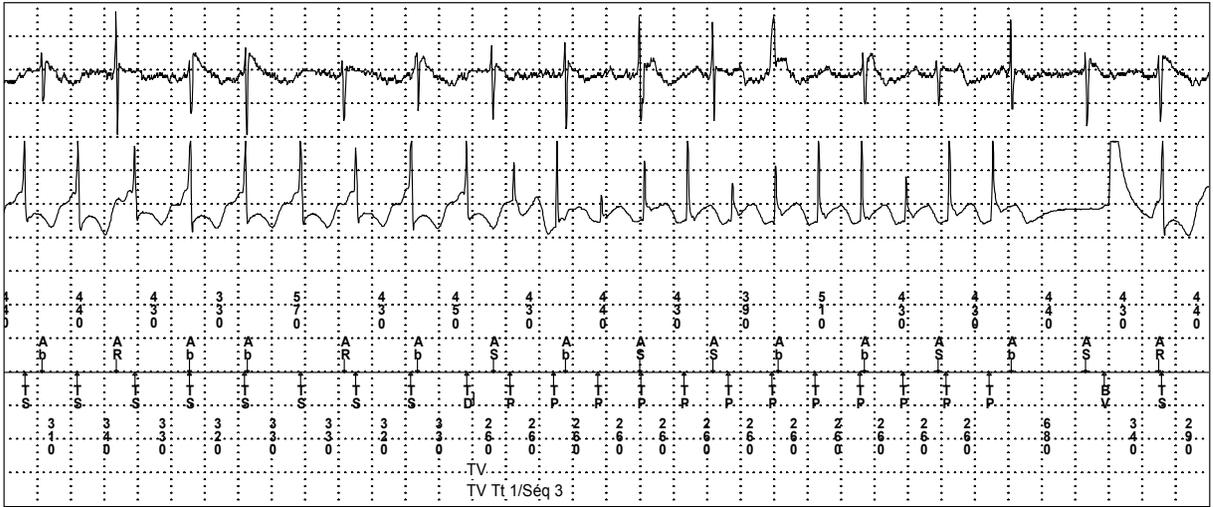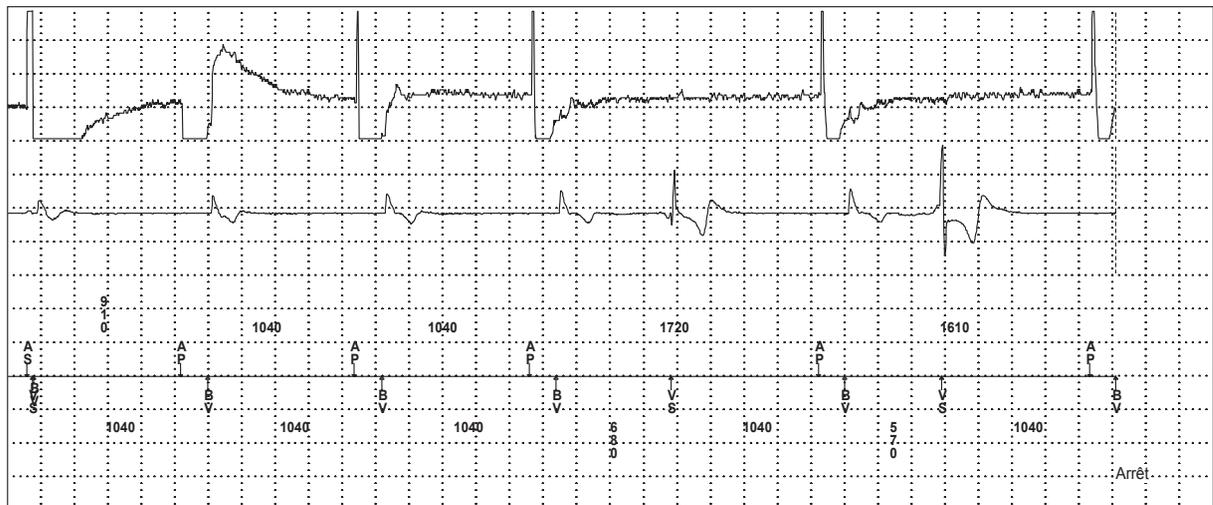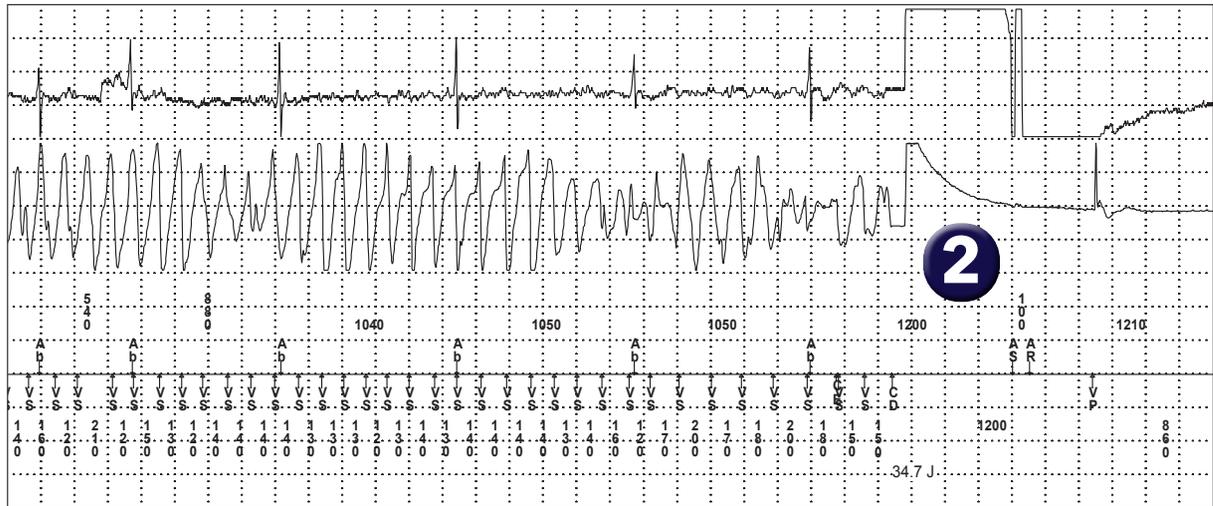
2 What is your final diagnosis?

Initially there is a regular monomorphic ventricular tachycardia; the first 3 bursts (treatment 1) and the first 3 ramps (treatment 2) are ineffective; a first shock (treatment 3) accelerates the arrhythmia which degenerates into VF with extremely short cycles; a maximum output shock results in termination.

Key messages

- The output of the first shock during VT can be programmed at maximum energy or at a lower energy (of the order of 10 to 15 Joules).

- This trace shows the main drawback of programming a 10 Joule shock in the VT zone, namely the pro-arrhythmogenic risk.

- Below a certain value, which varies depending on the patient and is directly linked to the defibrillation «threshold», not only can a shock prove ineffective, but it can also cause a monomorphic VT to accelerate and disorganise into a polymorphic arrhythmia, compromising the patient's survival.

- This tracing shows an extremely rapid, polymorphic arrhythmia induced by the first shock. Induced arrhythmias are often associated with very short ventricular cycle lengths; it is very rare to observe such rapid cycle lengths (in the order of 140 to 150 ms) in spontaneous arrhythmias.

- There are a number of advantages to programming an initial shock of moderate output (10-15 Joules): 1) this output is very often sufficient to terminate an episode of VT; 2) the charge time for this output is very short, even if the few seconds saved compared to a maximum energy shock is not clinically important when the shock occurs after 3 burst sequences +/- 3 ramp sequences (more than one minute of arrhythmia); 3) battery consumption is lower for a shock at 10 Joules compared to 41 Joules, although battery wear is minimally affected if only a limited number of shocks are delivered

- Other factors to be considered when programming shock output are: 1) despite the fact that most patients are still conscious during shocks delivered for VT, the pain due to the shock does not influence decisions surrounding the output of the first shock, since it is difficult to demonstrate a direct relationship between shock output and pain severity; 2) various studies have demonstrated the deleterious effects of device based shocks and their association with adverse outcomes; it therefore seems logical to assume a shock of 10-15 Joules may have fewer negative consequences than a shock of 41 Joules.

11 programming a first shock at maximum output in the VT zone

Patient

Male implanted with a single chamber defibrillator (Visia XT VR) for ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VT	6	35J	Yes	12	16-Mar-2020	09:03	:57	188	194	Rest

1 What diagnosis is suggested by the interval plot?

The plot shows an episode of ventricular arrhythmia with acceleration into the VT zone; the first 3 bursts and first 3 ramps do not revert the arrhythmia; a maximum output shock terminates the arrhythmia.

TV
TV Tt 1 Burst

TV
TV Tt 1/Séq. 2

TV
TV Tt 1/Séq. 3

TV
TV Tt 2 Ramp

② What is your final diagnosis?

Regular monomorphic ventricular tachycardia; the first 3 bursts (treatment 1) and first 3 ramps (treatment 2) are ineffective; maximum output shock (treatment 3) terminates the arrhythmia.

Key messages
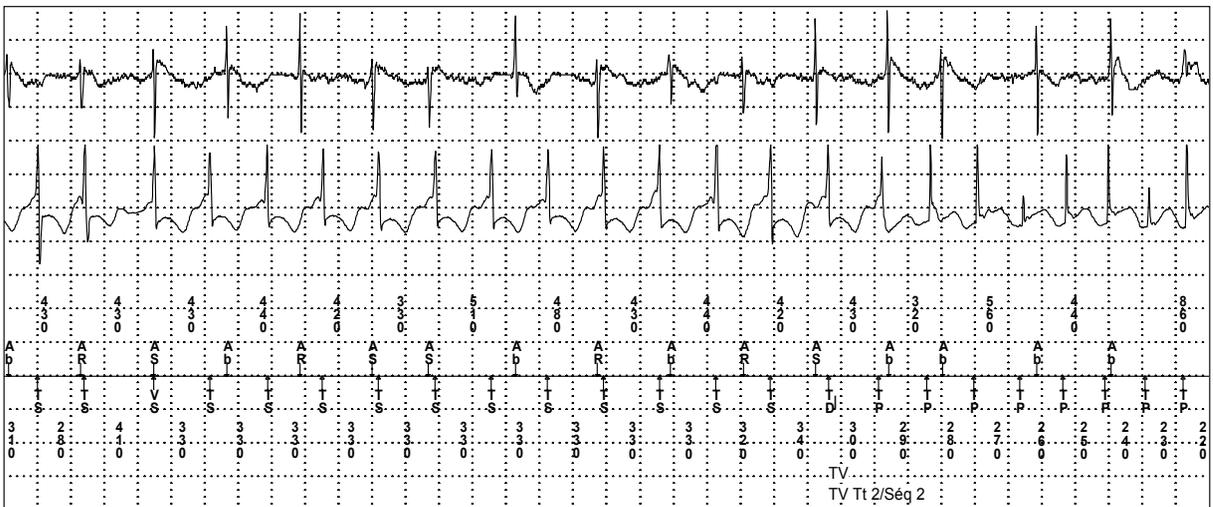
- Although there is no universal 'optimal' programming, the results of large studies concur on the need to reduce inappropriate or unnecessary therapies without compromising patient safety.

- Empirically programming a first shock of maximum energy in the VT zone, as in this example, reduces the risk of a pro-arrhythmogenic effect, increases the probability of terminating VT with the first shock, minimises the number of shocks delivered as far as possible and increases the probability of reverting AF if the shock is inappropriate

Oversensing

600		600		600		610		580		590	
	AR		AR		AR		AR		AR		AR
VS	TF●	TS		VS	TF●	TS		VS		VS	
260	330	600		270	330	610		590		580	

Arrêt
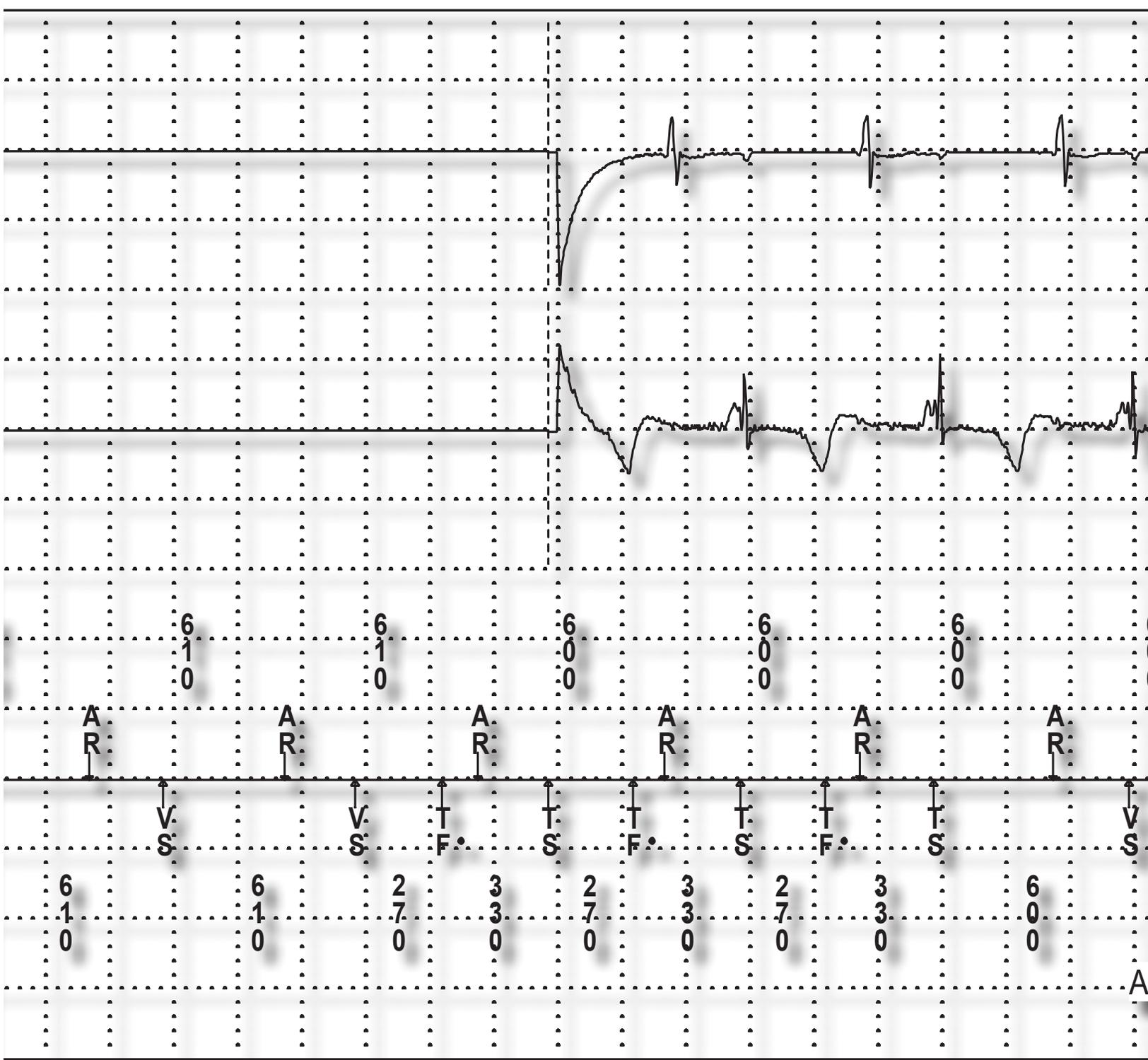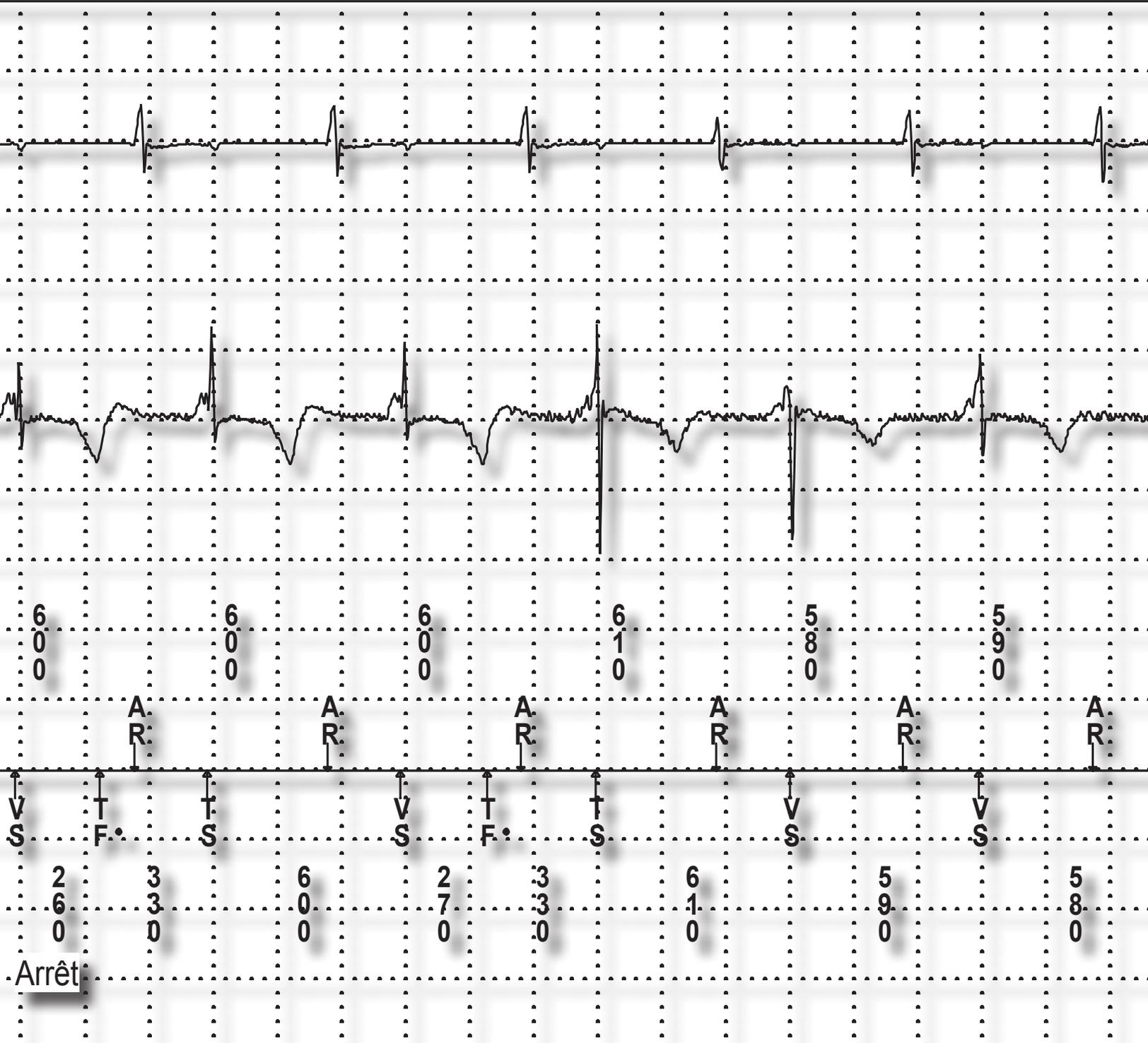
1 a special kind of plot

Patient

Male implanted with a primary prevention single-chamber defibrillator (Cobalt VR) for ischaemic cardiomyopathy; multiple episodes of NSVT stored in memory.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VT-NS				928	18-Mar-2022	18:29	:04	210		Active

● V-V Paced   ○ V-V Sensed

VF = 250 ms   VT = 330 ms
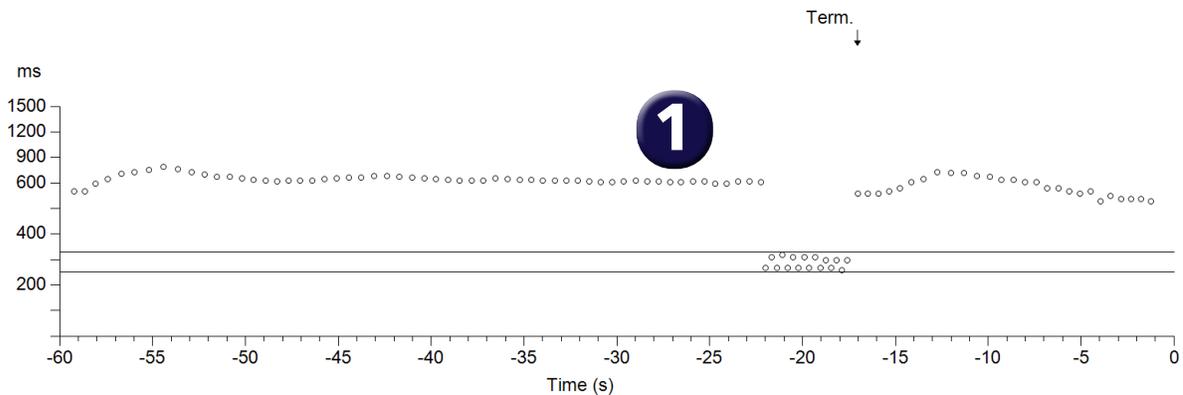
1 What diagnosis is suggested by the interval plot?

The plot shows a characteristic 'railroad track' appearance; initially the rhythm is regular with intervals around 600 ms, which is compatible with a sinus tachycardia; then the plot shows a 'railroad track' appearance alternating between 2 intervals, the first at around 250 ms, the second at around 350 ms; it is important to note that the sum of these 2 intervals (250 +350 ms) is equal to the initial value of 600 ms.

These 2 elements (railroad track appearance + sum of intervals equal to the initial value) are very suggestive of oversensing of a physiological cardiac signal (T wave, P wave, double counting of the R wave); the duration of the intervals (250 and 350 ms) makes the hypothesis of double counting of the R wave very unlikely (one of the two intervals would be much shorter, bordering on the ventricular blanking period); an analysis of the EGM helps clarify the diagnosis.

EGM1: RVtip to RVring
(1 mV)

EGM2: Can to RVcoil
(1 mV)

Markers

V-V (ms)

| | V S | 6 1 0 | V S | 6 1 0 | V S | 6 2 0 | V S | 6 2 0 | V S | 6 0 0 | V S | 6 0 0 | V S | 6 2 0 | V S | 6 2 0 |

2

| V S | 6 1 0 | V S | 2 7 0 | S | 3 1 0 | S | 2 7 0 | S | 3 2 0 | S | 2 7 0 | S | 3 1 0 | S | 2 7 0 | S | 3 1 0 | S | 2 7 0 | S | 3 1 0 | S | 2 7 0 | S | 3 0 0 | S | 2 7 0 | S | 3 0 0 | S | 2 6 0 | S | 3 0 0 | S | 5 6 0 | V S | 5 6 0 | V S | 5 6 0 |

Termination

| V S | 5 7 0 | V S | 5 8 0 | V S | 6 1 0 | V S | 6 5 0 | V S | 7 3 0 | V S | 7 2 0 | V S | 7 2 0 | V S | 6 9 0 | V S | 6 8 0 | V S | 6 4 0 | V S |

② What is your final diagnosis?

The EGM shows 2 alternating signals of different morphology, a high-frequency "sharp" signal corresponding to the QRS complex and a lower-frequency, "softer" signal corresponding to the T wave; there is also an alternating pattern to the duration of the intervals: a short cycle (260-270 ms) and a longer cycle (300-320 ms).

The 2 intervals fall within the VT zone programmed between 330 and 250 ms (TS markers); however, the oversensing is intermittent and the counters are not filled, which explains the NSVT classification.

Therefore, the final diagnosis is T wave oversensing during sinus rhythm

Key messages

- Analysis of the interval plot can sometimes suggest certain diagnoses; analysis of the EGM can confirm them.

- A systematic analysis of episodes classified as NSVT by the device sometimes leads to unexpected diagnoses, such as T wave oversensing.

- T wave oversensing is associated with a typical appearance of alternation between 2 morphologically different signals that include a high-frequency signal (R wave) and a low-frequency signal (T wave); for each cardiac cycle, the device not only counts the R wave, but also the T wave as a second additional signal, resulting in a doubling of the heart rate; the magnitude of the variation in cycle length (RT intervals and TR intervals) is generally more pronounced for slow heart rates (short RT intervals and long TR intervals) but is less pronounced during exercise (similar RT and TR intervals) and in patients with a long QT interval.

- Although unrelated to the problem described in this trace, the programming in this patient is surprising, the use of the VT counter (which implements consecutive cycles and resets following a single undersensed event) for such short cycle lengths (250 ms intervals) being very questionable ...

2 oversensing and risk of sudden death

Patient

Patient implanted with a dual-chamber defibrillator (Virtuoso DR) for ischaemic cardiomyopathy and hospitalised due to syncope followed by a shock from the device.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	1	35J	Yes	18	08-Jan-2014	11:57	:26	115/240	---/---	Active
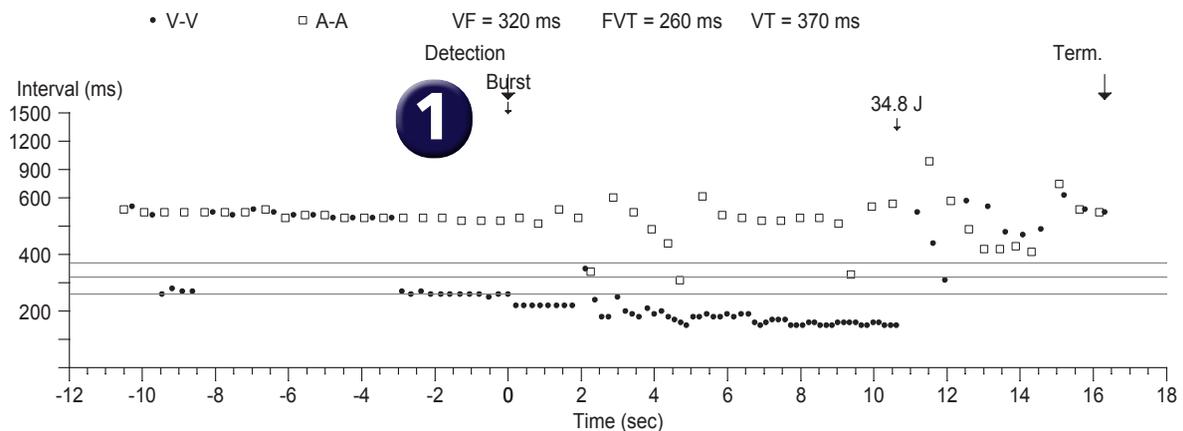
1 What diagnosis is suggested by the interval plot?

The plot shows an initial rhythm of just over 100 bpm with 1 :1 AV association that may correspond to sinus tachycardia ; this is followed by a sudden acceleration of the ventricular rhythm with cycles detected at the border between the FVT zone and the VF zone; a burst is delivered with acceleration of the rhythm into the VF zone; a maximum output shock terminates the arrhythmia.

2 | What is your diagnosis?

On the EGM, there is initially sinus tachycardia followed by oversensing of the T wave with cycles classified as either FVT or VF; there is alternation between 2 morphologically different signals, a high-frequency signal (R wave) and a low-frequency signal (T wave); the RT intervals are more or less equal to the TR intervals, which explains the absence of a 'railroad track' appearance on the interval plot; the VF counter is full (programmed at 12/16); the episode is classified as VF since at least one cycle out of the last 8 is classified in the VF zone (FS) and a burst during charging is delivered.

3 | What do you think of the cycle length of the burst?

The cycle length of the rapid pacing intervals during a burst is calculated from the average of the last 4 tachycardia cycles before the counters were completed; in the presence of T wave oversensing, the heart rate calculation is incorrect and there is a risk that the first cycle of the burst is delivered on the T wave (50% probability); this was the case in this example which explains the rest of the trace.

4 | What is the effect of the burst followed by a shock?

The burst degrades the ventricular rhythm into an extremely rapid and polymorphic arrhythmia, threatening the patient's life; the shock is effective and restores a viable rhythm.

117

Key messages

- This patient's device was implanted for primary prevention, i.e. he had never experienced a sustained, symptomatic ventricular arrhythmia before the defibrillator was fitted. A defibrillator is indicated because it can significantly reduce mortality; however, it should be remembered that in some patients, the defibrillator can paradoxically increase the risk of sudden death by inducing serious ventricular arrhythmias.

- T wave oversensing should be considered an emergency; even if there are algorithms to circumvent this, the risk of one or more inappropriate therapies being delivered is not zero.

- This tracing shows the potentially pro-arrhythmogenic effect of an ATP pacing sequence delivered for T wave over-sensing; in this example, the first cycle of the burst is delivered on the T wave, during a vulnerable period, which induces a polymorphic ventricular arrhythmia.

- As a general rule, ventricular arrhythmias induced by the device are usually very concerning because they are extremely rapid and polymorphic, and the effectiveness of the shock becomes essential to re-establish a viable rhythm. Oversensing of the T wave is enhanced by the presence of a low amplitude R wave, there is an increased risk of of under sensing of induced VF in these patients.

- The occurrence of an inappropriate shock due to T wave oversensing can also have consequences beyond the pain felt by a patient; in this setting, the shock is synchronised to either the R wave or the T wave; patients with T wave oversensing and a high defibrillation threshold are particularly at risk; in fact, as explained above, in the presence of T wave oversensing, there is a 50% chance that the shock will be delivered on the T wave and therefore in the vulnerable ventricular period; if the defibrillation threshold is high and close to the maximum capacity of the device, the upper vulnerability value is also high; therefore a shock delivered on the T wave has a very high probability of inducing ventricular fibrillation (due to the concept of upper limit of vulnerability) which will then be very difficult to cardiovert even with a maximum output shock (high defibrillation threshold).

3 which programming option should be used if the T wave is oversensed?

Patient

Patient implanted with a single-chamber defibrillator for Brugada syndrome; episodes of T wave oversensing recorded in memory.

1

Sensing Test

	Test Value	Permanent
Mode	VVI	AAIR<=>DDDR
AV Delay		220 ms
Lower rate	50 bpm	60 bpm

Last Sensing Measurement

18-Nov-2013
P Wave Amplitude	2.9 mV
R Wave Amplitude	1.4 mV

Sense Polarity

P Wave	Bipolar
R Wave	Bipolar

1 ## What do you think of the sensing values measured in this patient?

When the device is programmed in traditional bipolar mode, the amplitude of the R waves is low (1.3 mV), which explains the increased risk of T wave oversensing; in fact, the sensitivity profile in a defibrillator is said to be adaptive, with a sensitivity value that initially adapts to the amplitude of the QRS complex; when, the measured amplitude of the R wave is low, the defibrillator is permanently very sensitive (low sensitivity value throughout the cardiac cycle), with an increased risk of oversensing of extra- or intra-cardiac signals.

2

Sensing Test

	Test Value	Permanent
Mode	VVI	AAIR<=>DDDR
AV Delay		220 ms
Lower rate	50 bpm	60 bpm

Last Sensing Measurement

18-Nov-2013
P Wave Amplitude	2.8 mV
R Wave Amplitude	7.9 mV

Sense Polarity

P Wave	Bipolar
R Wave	Tip/Coil

2 ## Which parameter has been changed?

Sensitivity programming has been changed from bipolar to Tip/Coil (which corresponds to integrated bipolar sensing).

119

RV Impédance (bipolar)

dernière session   ohms
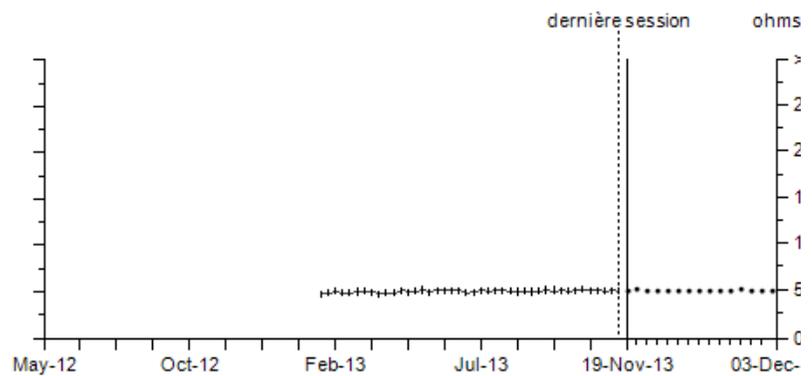
RV Threshold

Contrôle du seuil	Auto
Amplitude	2.25 V
Durée d'impuls.	0.40 ms
Dernière mesure	1.125 V à 0.40 ms
Date mesure	03-Dec-2013

dernière session   V à 0.40
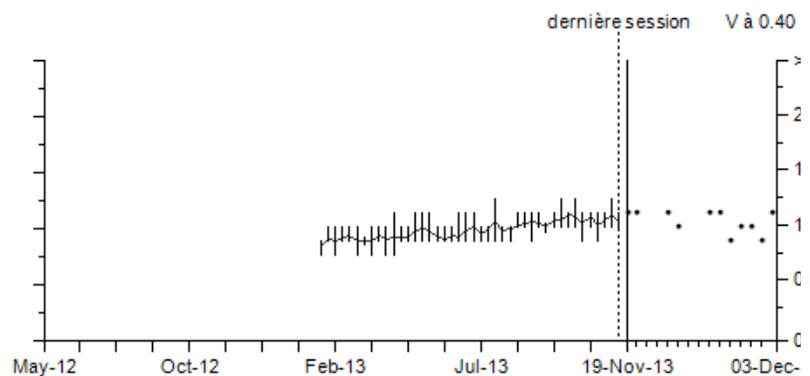
R wave Amplitude

Sensibilité	0.30 mV
Dernière mesure	6.5 mV

dernière session   mV

③

80 last. weeks (min/max/avg by week)   **15 last days**
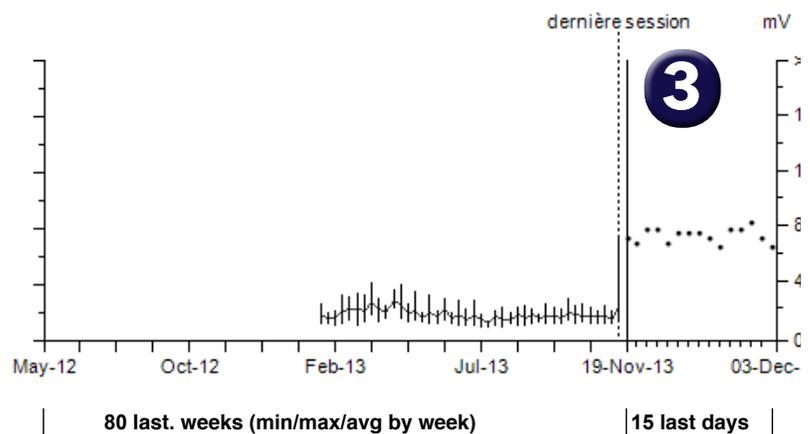
③ What was the effect of this change in programming?

There was a significant and sustained increase in the amplitude of the R wave, with measured values of between 6 and 8 mV.

Key messages

- In this example, T wave oversensing occurs in the presence of suboptimal ventricular sensing with small amplitude R waves; T wave oversensing is a problem often associated with poor quality R wave sensing.

- In this context, any modification of ventricular sensitivity (reprogramming the sensitivity from 0.3 mV to 0.6 or 0.9 mV) is inappropriate and even dangerous, with a significant possibility of undersensing of VF episodes.

- There is a specific programming feature in Medtronic™ defibrillators which may enable resolution of this difficult situation in certain patients and avoid repositioning the lead; it is possible to program ventricular sensing in either «true» bipolar mode (detection between the 2 distal electrodes) or in integrated bipolar mode (detection between the distal electrode and the right ventricular coil). In a large number of patients, the amplitude of the R wave measured is not significantly different between the 2 configurations; there is therefore no guarantee that the amplitude will be systematically greater in integrated bipolar; however, in certain patients presenting with a low amplitude R wave in a true bipolar configuration, reprogramming RV sensing vector to integrated bipolar sensing can significantly increase the size of the R wave and thus resolve the problem of T wave oversensing (better ratio of R wave amplitude to T wave amplitude); this is a major competitive advantage, since at present, Medtronic™ is the only company offering this feature.

- In this patient, this programming change enabled us to obtain a more acceptable R wave that allowed the device to function properly and prevented further episodes of T wave oversensing.
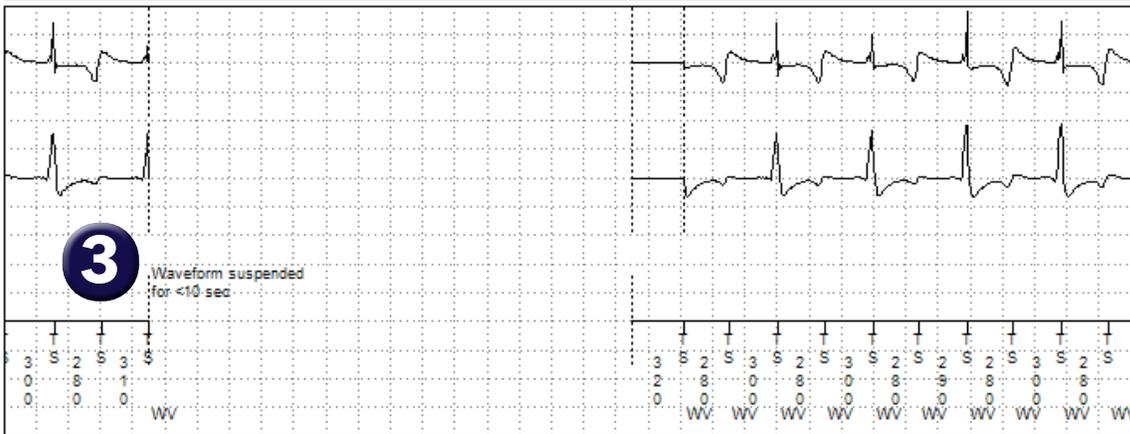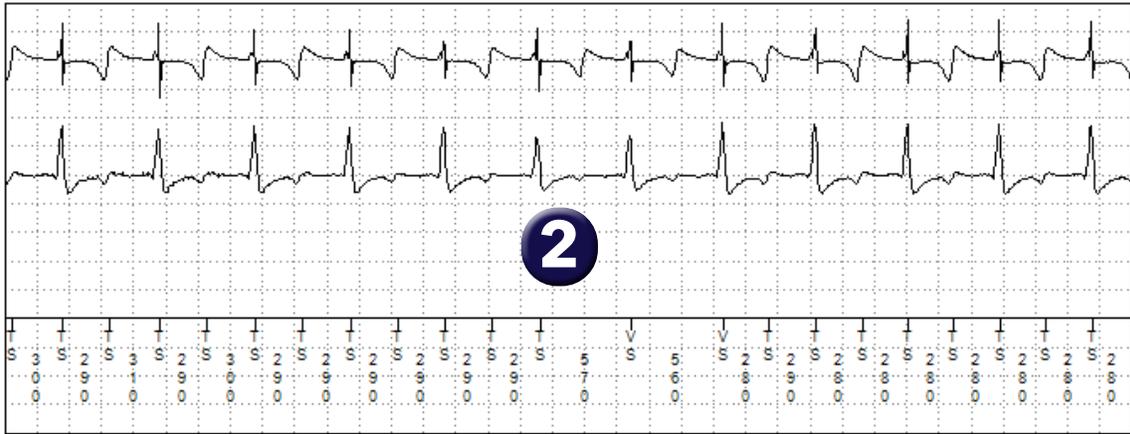
4 the unexpected behaviour of an algorithm

Patient

Male implanted with a single-chamber defibrillator (Cobalt VR) for primary prevention of ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
SVT-Wavelet				546	23-Feb-2022	11:25	:11	207	207	Active

- V-V Paced   ○ V-V Sensed

  VF = 250 ms   VT = 330 ms

1

1 How was this episode classified?

This episode was classified as supraventricular tachycardia following Wavelet analysis.

2 What is your diagnosis?

This is an episode of T wave oversensing.

3 Has therapy been provided?

When the VT counter is filled after 36 consecutive cycles classified as VS (TS marker), discrimination based on Wavelet analysis classifies the episode as SVT and therefore inhibits therapies; analysis then continues cycle by cycle with inhibition (WV marker).

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
SVT-Wavelet				546	23-Feb-2022	11:25	:11	207	207	Active

Match 88 %   No Match 0 %   Match 88 %   No Match 0 %

Match 85 %   No Match 0 %   Match 88 %   No Match 0 %

20 ms
— QRS
······· Template
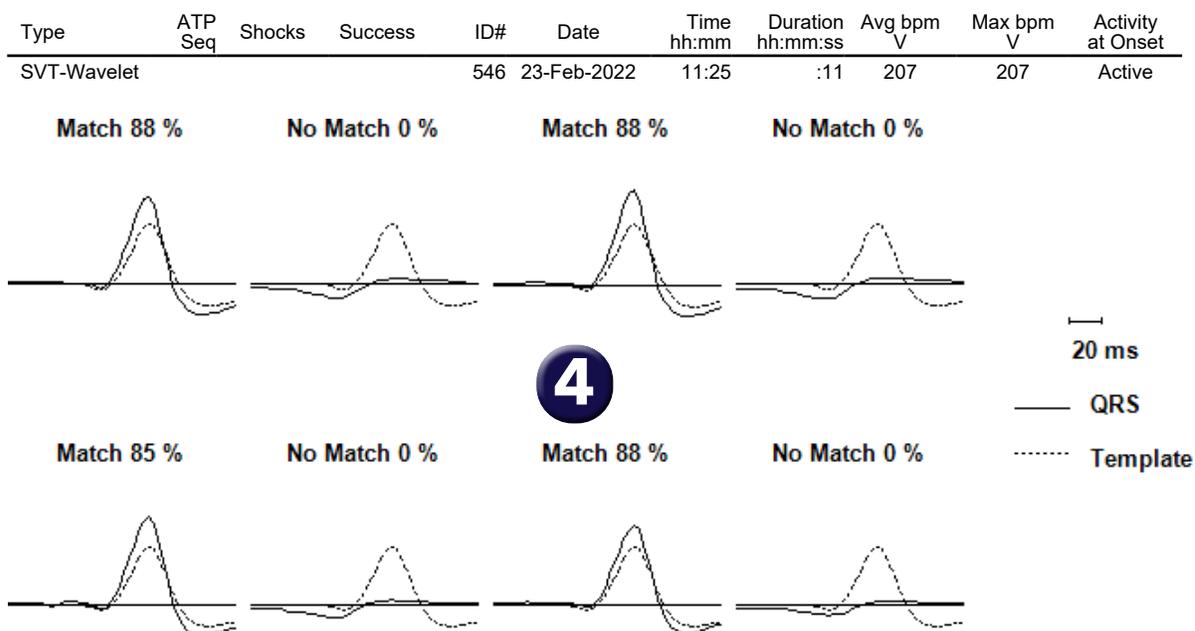
4 How do you analyse the Wavelet analysis?

In the presence of T wave oversensing, the defibrillator senses the R wave and T wave alternately; as expected, 50% of the complexes (the R waves) are judged to be similar to the reference morphology with a percentage match higher than the threshold value (here between 85 and 88%), the other 50% of complexes (the T waves) are judged to be different with a percentage match of 0%.

Key messages

- To avoid inappropriate therapies related to T wave oversensing, it is necessary to : 1. understand the reason for oversensing in order to optimise programming (for example, change the sensing polarity in the presence of a small amplitude R wave), 2. program one or more algorithms enabling therapies to be avoided if oversensing occurs.

- Wavelet analysis was initially designed to differentiate between VT and SVT; this tracing shows that this algorithm can also be used favourably in a completely different context; here the defibrillator «makes the wrong diagnosis», diagnosing the episode as SVT, but this still avoids inappropriate therapies.

- When the T wave is oversensed, one out of two cycles is considered similar to the sinus rhythm template, which explains the diagnosis of SVT; in fact, at least 3 cycles out of 8 must be correlated; this algorithm therefore constitutes a first line of defence against inappropriate therapies when the T wave is oversensed.

- However, there are certain limitations: this algorithm only works if the frequency does not exceed the SVT limit (260 ms is the nominal cycle length); similarly, on a dual or triple chamber defibrillator, when PR Logic is programmed simultaneously with Wavelet, the latter is not applied if PR Logic considers the ventricular rhythm to be faster than the atrial rhythm (which is the case when the T wave is oversensed); in these 2 cases, the Wavelet algorithm will not be implemented and another algorithm is then required to avoid inappropriate therapies.

⑤ use of a specific algorithm

Patient

Male implanted with a single-chamber defibrillator (Cobalt VR) for primary prevention of ischaemic cardiomyopathy. (same patient as above).

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
V. Oversensing-TWave				3025	23-Mar-2022	15:41	:09	250	---	Active

- V-V Paced   ○ V-V Sensed

VF = 250 ms   VT = 330 ms   ①
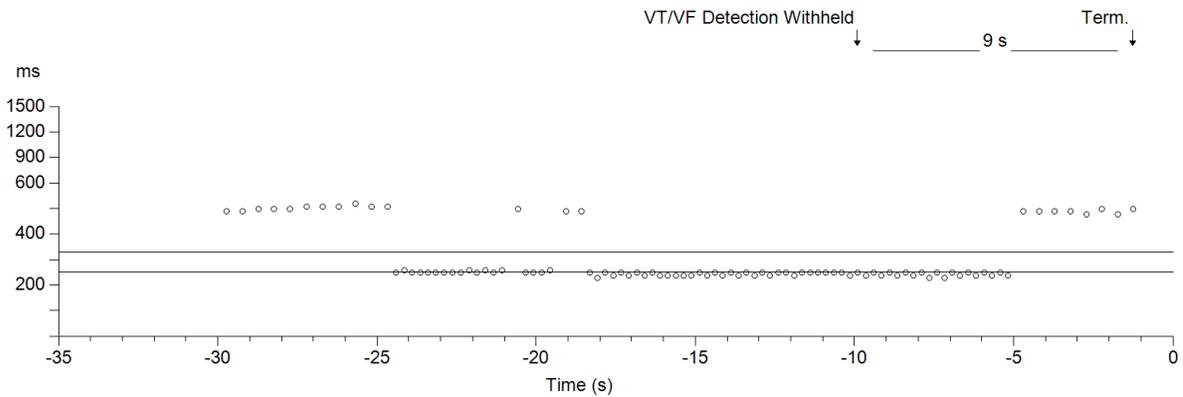
① How was this episode classified?

This episode was classified as T wave oversensing.
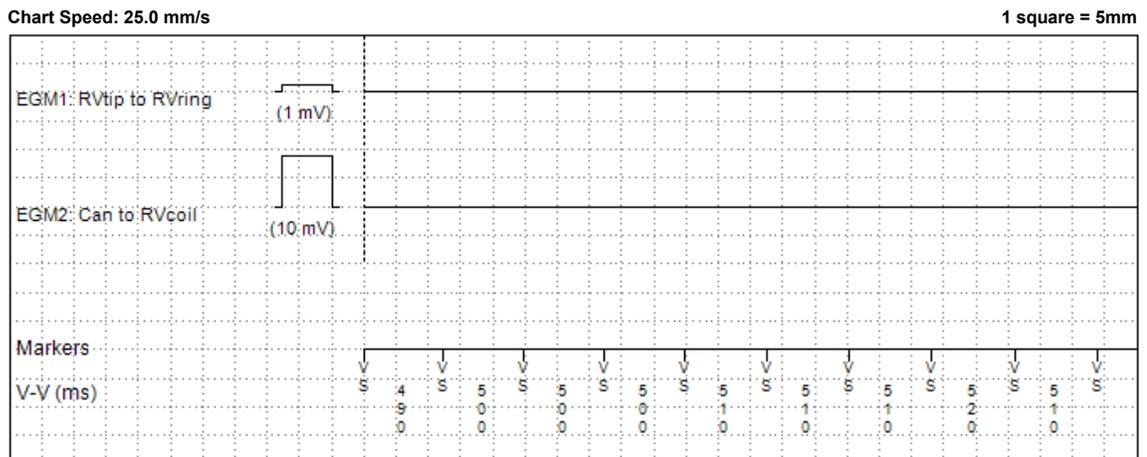
Termination

2 What is your diagnosis?

This is an episode of T wave oversensing.

3 Has therapy been provided?

When the combined counter is full (35 cycles classified as VT or VF), the defibrillator concludes that the T wave has been oversensed and inhibits therapies; the analysis then continues cycle by cycle with inhibition (T wave marker).

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
V. Oversensing-TWave				3025	23-Mar-2022	15:41	:09	250	---	Active

No Match 0 %   Match 88 %   No Match 0 %   Match 88 %

20 ms
—— QRS
······· Template

No Match 0 %   Match 88 %   No Match 0 %   Match 88 %
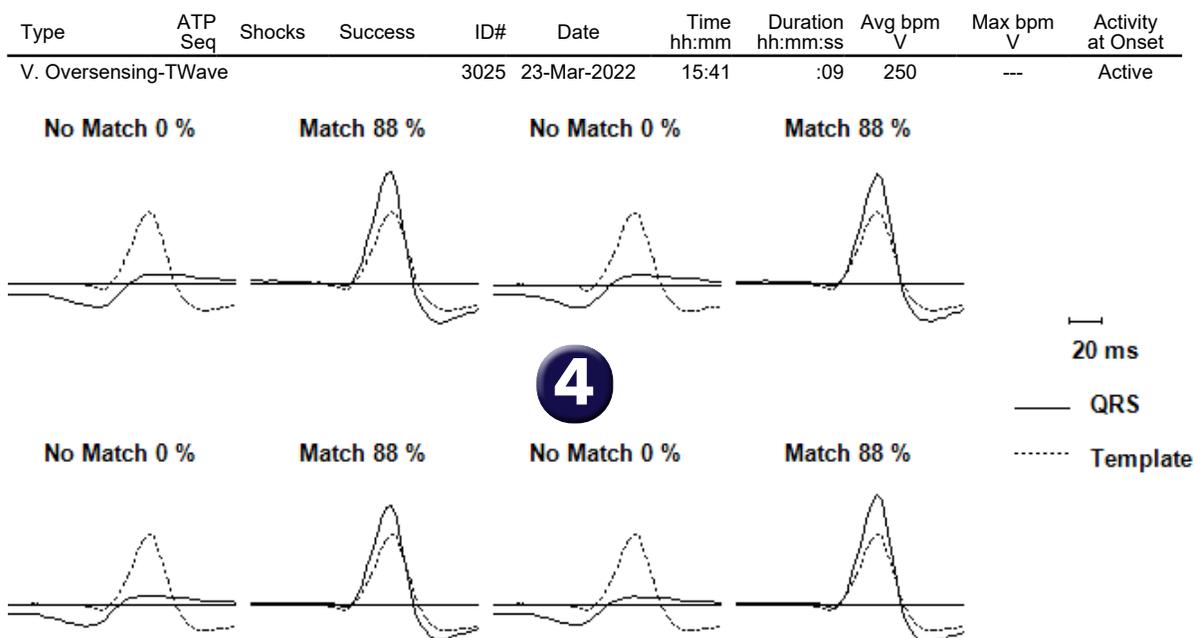
4 How do you analyse the Wavelet analysis?

Wavelet would have concluded the diagnosis of SVT (50% of cycles considered similar); as previously indicated, Wavelet was not used as the ventricular cycles were too short (faster than the programmed SVT limit of 260 ms).

Key messages

- In this episode of T wave oversensing delivery of therapies is inhibited following intervention by an algorithm specifically designed for this purpose.

- Visually, making the diagnosis of T wave oversensing is not very difficult for a clinician, given the alternation between 2 signals with different appearances and fixed coupling; this algorithm present on Medtronic™ defibrillators is based on this principal.

- R waves and T waves are differentiated by means of a differential filter which amplifies the difference between the 2 signals; the algorithm recognises T wave oversensing by identifying the repetition of sequences alternating between 2 signals of differing frequency (a high frequency signal, a softer signal) with fixed intervals (fixed RT intervals, fixed TR intervals); various parameters are therefore analysed and if the diagnostic criteria are met over 6 consecutive intervals, the T wave oversensing counter is incremented by +1 ; if a criterion is not met, all 6 consecutive intervals are classified as normal; the next group of 6 intervals is then assessed using a sliding window; as long as 4 of the last 20 sequences meet the T wave discrimination criterion, the device retains the diagnosis of T wave oversensing and the therapies are not delivered.

- This algorithm is nominally programmed on.

- This algorithm works even if the detected frequency exceeds the programmed SVT limit (unlike Wavelet or PR Logic).

⑥ oversensing and integrated bipolar mode

Patient

Male with ischaemic cardiomyopathy implanted with a dual-chamber defibrillator (Evera XT DR), hospitalised for pre-syncope; history of paroxysmal AF.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
High Rate-NS				2	10-Sep-2016	16:46	:01	269/305		Rest

• V-V   □ A-A   VF = 300 ms
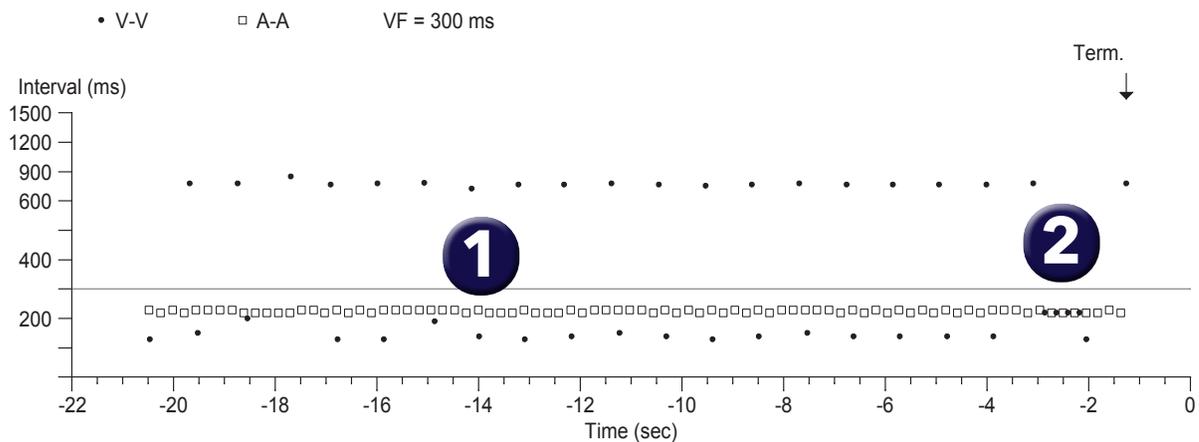
① How would you describe the start of the interval plot?

The plot shows rapid, regular, atrial activity and a railroad-track appearance to the ventricular cycles, with a very short cycle (at the limit of the programmed blanking value) and a longer cycle.

② How would you describe the end of the graph?

Over a few cycles, the ventricular rate becomes very rapid such that it is superimposed on the atrial rate.

EGM1: Atip to Aring

(1 mV)

EGM3: RVtip to RVring

(1 mV)

A-A (ms):

Markers:

V-V (ms):

③ What is your diagnosis?

The EGM confirms the existence of a regular atrial tachycardia with cycles of 220-230 ms and reveals an oversensing at the ventricular channel of a signal corresponding to atrial activity at the end of the cycle; the functioning of the ventricular adaptive sensing explains why previous atrial signals of equivalent amplitude are not sensed by the ventricular probe, the device being less sensitive at the beginning of the cycle and the sensitivity adapting to the amplitude of the QRS complex.

④ How do you explain the occurrence of pre-syncope?

The EGM shows a ventricular pause of around 2 seconds, which may explain the occurrence of presyncope; during this cycle, there is no spontaneous QRS complex; the sensitivity is therefore not readjusted, the device remains very sensitive and oversensing persists, explaining the absence of ventricular stimulation associated with the pause; the oversensing stops following the onset of a QRS complex (which readjusts the sensitivity level).

Key messages

- This tracing is an example of oversensing of atrial activity by the ventricular channel during an episode of atrial tachycardia.

- Oversensing is particularly concerning in pacing-dependent patients because 1) it can lead to ventricular pauses, 2) oversensing can be prolonged in the absence of spontaneous QRS complexes, with the sensitivity level remaining at a maximum and adapting to the amplitude of the oversensed signals, which are often small.

- Oversensing of atrial depolarisation by the right ventricular lead is rare and occurs mainly in patients implanted with an integrated bipolar lead; in a patient in sinus rhythm, the right ventricular lead detects both atrial and ventricular depolarisation, as the PR interval is longer than the ventricular blanking; if the patient has complete atrioventricular block, oversensing of the P wave may inhibit ventricular pacing and cause asystole.

- Oversensing of atrial depolarisation during atrial flutter or atrial tachycardia can cause both inappropriate therapies and asystole, if the patient is dependent.

- The oversensing of atrial signals by the ventricular lead is more likely in 2 situations: 1) displacement of the right ventricular lead at the atrio-ventricular junction (coinciding with a drop in the measured R wave amplitude); 2) positioning of an integrated bipolar lead close to the tricuspid annulus, with the distal coil straddling the valve (associated with a preserved R wave amplitude); 3) programming a Distal-Coil sensing vector with a bipolar lead whose coil is too close to the RA.

- Atrial oversensing can also occur in more exceptional circumstances: 1) right ventricular lead inadvertently placed in the coronary sinus; 2) insulation defect in the atrial portion of the ventricular lead resulting in oversensing of atrial activity; 3) interaction between the atrial lead and the right ventricular lead, with the atrial lead coming into contact with the ventricular lead and generating a signal at the time of atrial systole.

- Several solutions exist to avoid the occurrence of inappropriate therapies or ventricular pauses in a pacing-dependent patient: 1) reduce the ventricular sensitivity to prevent sensing of the additional signal linked to atrial activity; however, this programming modification is accompanied by an increased risk of undersensing VF, VF induction may be required to check that the induced VF is correctly detected with the new sensitivity value; 2) oversensing of atrial activity may require the defibrillation lead to be repositioned (new defibrillation lead if DF4 system or addition of a pace/sense lead if DF1 system).

7 electric shock during a barbecue

Patient

Male with ischaemic cardiomyopathy implanted with a single-chamber defibrillator (Visia AF MRI XT VR) who received an electric shock during a barbecue.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VF	0	35J	Yes	7	14-Oct-2022	09:40	:14	500	---	Active
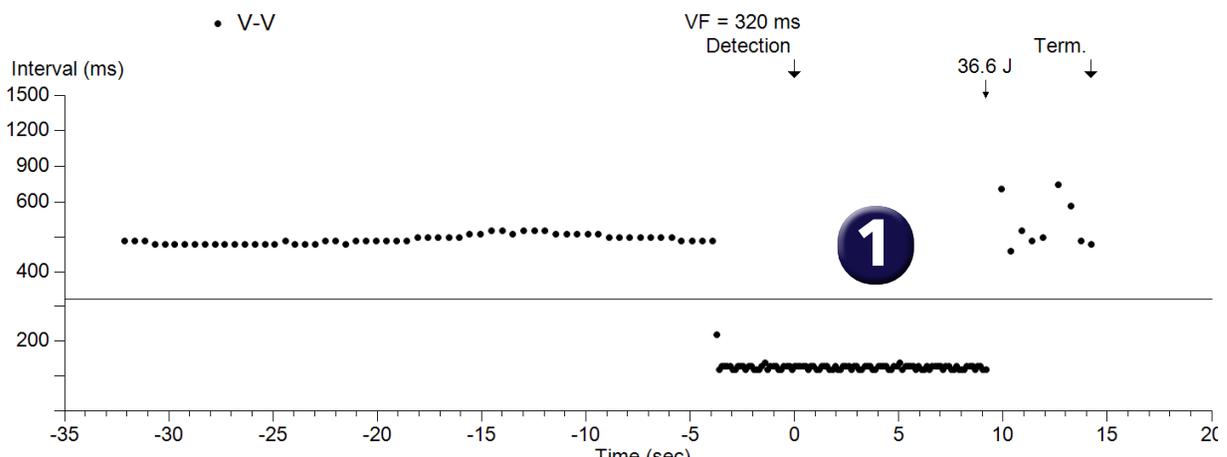
1 Does the interval plot suggest a ventricular rhythm disorder or a problem with oversensing?

The plot shows a sudden shortening of the ventricular cycle length which becomes very short, falling into the VF zone at the limit of the programmed blanking value (around 120 ms); the existence of these very short cycles makes it unlikely that this episode is physiological and related to a true episode of ventricular arrhythmia; the most likely diagnosis is therefore that of oversensing with an electric shock that interrupts oversensing.

2 What is your diagnosis?

The EGM shows saturation of the baseline on the 2 channels (bipolar channel and shock channel), the signals observed on the shock channel being of higher amplitude; this is characteristic of oversensing due to electromagnetic interference (50 Hz); these signals are detected as "FS" by the defibrillator; when the FS counter is reached (probabilistic counter 30/40), the device charges its capacitors and delivers a shock after confirming that at least 2/5 cycles are fast; after the shock sinus rhythm reappears.

Key messages

- The risk of electromagnetic interference with an implantable defibrillator has been frequently described in the hospital environment, in the patient's home or during professional activities; interference can occur by conduction if the patient is in direct contact with the emitting source or by radiation if the patient is located within an electromagnetic field.

135

- The newest defibrillators are protected against most sources of interference that patients may encounter in their daily lives; interfering signals are typically filtered, with analysis restricted to a narrow bandwidth corresponding to physiological signals (high-pass and low-pass filters); however, the high adaptive sensitivity required in a defibrillator for correct detection of signals during ventricular fibrillation may favour detection of non-physiological signals falling within the same bandwidth.

- Signals due to electromagnetic interference may not be filtered appropriately with consequences of varying severity, ranging from occurrence of inappropriate therapies, inhibition of pacing in a dependent patient, inappropriate fallback due to incorrect diagnosis of supraventricular arrhythmia, rapid ventricular pacing synchronised to atrial oversensing, suspension of therapy detection or fallback to an asynchronous mode; in exceptional cases, interference with a high-intensity field can cause permanent circuit damage.

- The diagnosis of electromagnetic interference is based on confirmation of exposure to a source at the time of the episode and oversensing of characteristic signals (fast, regular and saturating the baseline).

- If the oversensing is prolonged, a single electric shock is usually sufficient to interrupt the oversensing, as the patient usually stops the offending activity immediately.

- Electromagnetic interference is more frequent with an integrated bipolar lead than with «true» bipolar detection, as the detection antenna is wider; the characteristic high-frequency signals, which are obviously non-physiological, are detected on available atrial and ventricular channels (possible diagnoses of bi-tachycardia or AF + VF) and are generally of greater amplitude on the shock channel than on the sensing channel.

8 an unexpected cause of syncope

Patient

Patient implanted with a dual-chamber defibrillator (Evera MRI XT DR) for episodes of VT due to ischaemic cardiomyopathy; patient in third degree AV block with episodes of syncope.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	0			129	13-Oct-2022	10:11	:14	545/240	- - -/---	Active
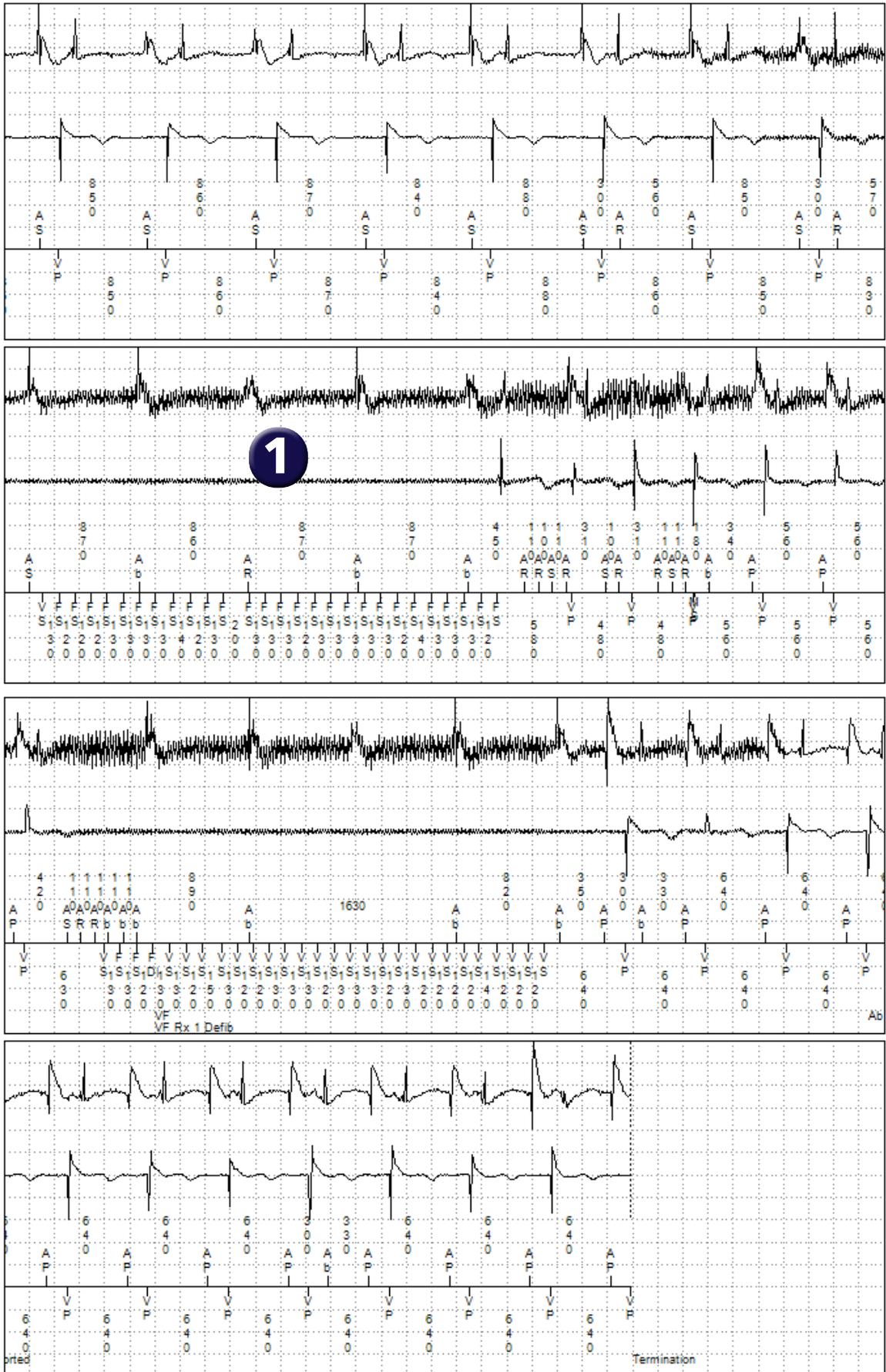
1 What is your diagnosis?

The EGM shows a characteristic feature of oversensing of electromagnetic interference with saturated signals on both channels.

2 What causes fainting?

Electromagnetic interference leads to saturation of the baseline with oversensing of very rapid ventricular cycles that fall within the VF zone; the oversensing inhibits ventricular pacing resulting in a ventricular pause and loss of consciousness in this dependent patient; the ventricular pause terminates with the occurrence of a spontaneous ventricular beat.

Key messages

- Ventricular oversensing of small amplitude signals (myopotentials, 50 Hz, etc.) in a dependent patient is doubly problematic in that 1. oversensing may be prolonged because the sensitivity level does not readjust following the detection of spontaneous ventricular activity 2. the oversensing inhibits pacing, which may lead to syncope.

- The main preventive measure is to identify the source of radiation and avoid using certain poorly insulated instruments; as the patient was being monitored remotely, an alert was received the next day linking the episode to the use of a poorly insulated household appliance.

9 shock during surgery

Patient

Man implanted with a triple-chamber defibrillator (Viva Quad XT CRT-D) for secondary prevention; electric shock delivered during shoulder surgery.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	0	35J	Yes	3	20-Feb-2015	13:25	:24	333/316	- - -/429	Active
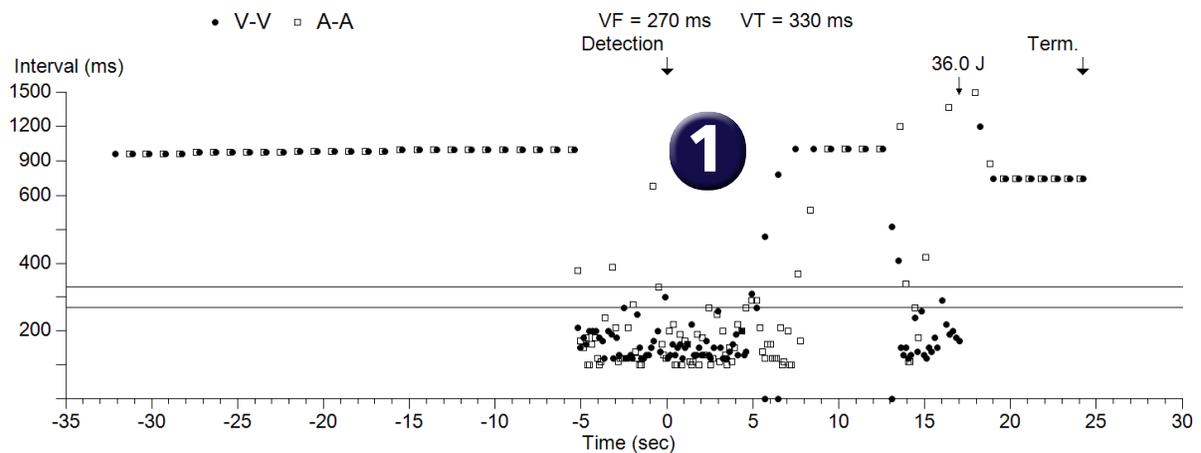
1 Does the interval plot suggest a ventricular rhythm disorder or a problem with oversensing?

The plot shows a sudden and simultaneous shortening of the ventricular and atrial cycle length, which become very short, within the VF zone, at the limit of the programmed blanking value (around 120 ms); the sudden and simultaneous acceleration of the atrial and ventricular cycles makes it highly unlikely that this episode is physiological and corresponds to a double tachycardia; therefore the most likely diagnosis is oversensing with an electric shock interrupting the oversensing.

EGM1: Atip to Aring

(1 mV)

EGM3: RVtip to RVring

(1 mV)

A-A Interval (ms)

Markers

V-V Interval (ms)

2 What is your diagnosis?

The EGM shows extremely polymorphic and clearly non-physiological signals in the atrial and ventricular channels; the oversensing is intermittent, which explains why the first charge is interrupted; when the oversensing resumes, the capacitors are already partially charged, so the electric shock is delivered after a very short charge time; the diagnosis

is obvious in this setting since the electric shock occurred during the use of diathermy during surgery.

Key messages

- On this trace, the appearance of the EGM is characteristic of oversensing related to the use of diathermy: polymorphic, very rapid, non-physiological signals are present on both channels.

- The diagnosis is usually obvious from the context in which the shock occurs.

- Receiving an electric shock can be a very painful experience that some patients find very distressing; some electric shocks are unavoidable... on the other hand, some electric shocks must be avoided at all costs!

- Some simple measures should be implemented when performing planned or emergency surgery: the surgeon should be advised to use the electrocautery device in bipolar mode, for short periods of time, and to place the plates at a distance from the unit so as to keep the defibrillation system outside the field generated by the electrocautery device; above all, the defibrillator should be temporarily deactivated to completely eliminate the risk of interference, and the patient should be monitored, with an external defibrillator available if necessary.

- Two options may be employed for deactivating the device: application of a magnet over the box or reprogramming of the device; application of a magnet is sometimes preferred because 1) in the event of true arrhythmia compromising the patient's survival, the medical team can immediately reactivate the system by removing the magnet (resumption of tachycardia detection immediately upon removal of the magnet); 2) absence or delay in reactivation of therapies is not uncommon when the defibrillator has been reprogrammed.

10 ventricular cycles too short to be physiological

Patient

Male implanted with a triple-chamber defibrillator (Claria MRI Quad CRTD); NSVT episodes recorded in memory.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
High Rate-NS				142	22-Jan-2022	06:56	:01	67/343		Rest
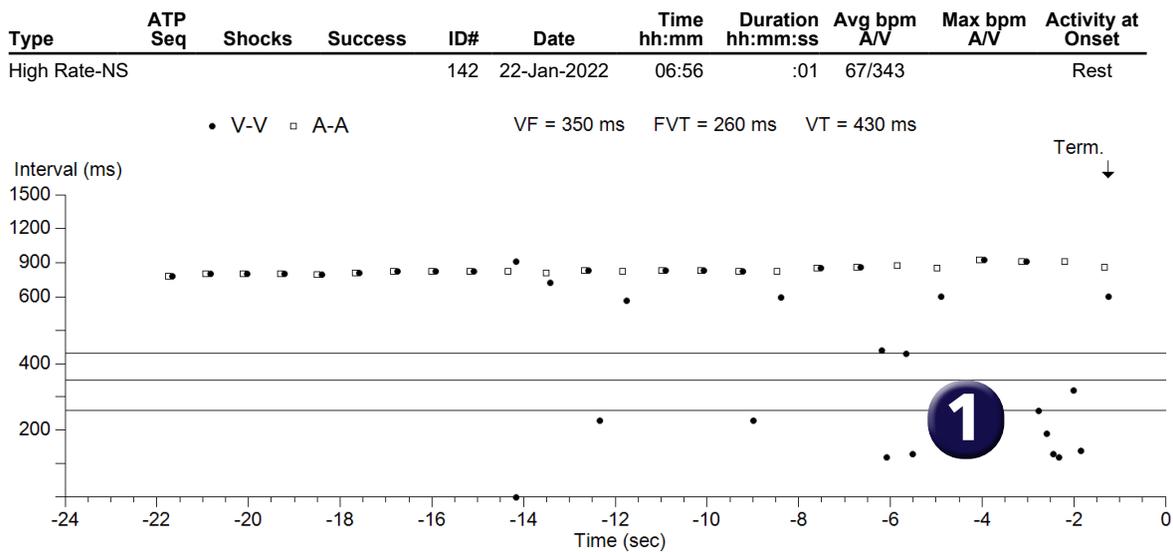
1 Is the appearance of the interval plot in favour of an episode of non-sustained ventricular arrhythmia?

The plot shows detection of a few rapid cycles followed by detection of a succession of cycles in the VF zone explaining the diagnosis of NSVT; the fact that some cycles are extremely short at the blanking limit of 120 ms and the duration of cycles varies from one cycle to another makes the diagnosis of true ventricular arrhythmia rather unlikely and instead suggests a problem of oversensing.

Termination
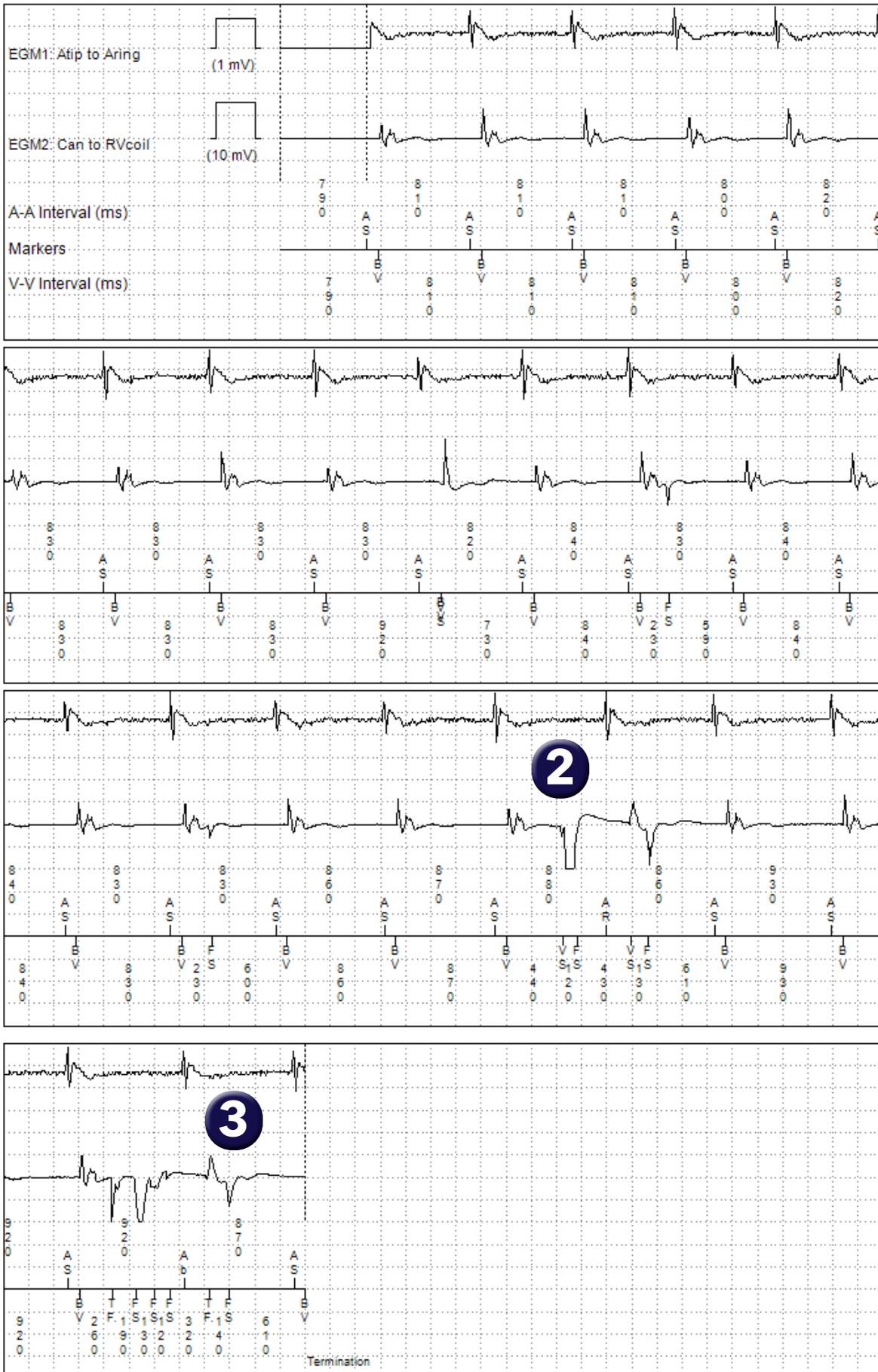
2 How do you analyse these complexes?

The EGM shows non-physiological signals on the ventricular channel; the cycle length is clearly non-physiological with an interval corresponding to the limit of the programmed blanking; the signal is of large amplitude, it saturates the amplifiers and is characteristic of a ventricular lead fracture; these signals are called 'make-break' potentials.

3 How do you analyse this salvo?

This appearance is also highly suggestive of lead fracture, with the detection of NSVT with very short cycles and a characteristic EGM appearance.

Key messages

- The ventricular lead is the weak link in the defibrillation system, with the number of malfunctions varying from model to model.

- Following a lead fracture, the diagnosis must be made as quickly as possible to avoid inappropriate therapies and to ensure that the system remains effective during an episode of ventricular arrhythmia.

- The systematic use of remote monitoring has considerably reduced the time between onset of dysfunction and diagnosis, resulting in a major reduction in adverse outcomes.

- Various manufacturers have proposed different algorithms for early diagnosis and/or inhibition of therapy when the diagnosis of ventricular oversensing due to lead dysfunction is made.

- LIA (Lead Integrity alert) is an algorithm incorporated into all modern Medtronic™ defibrillator platforms, enabling early diagnosis and a rapid alert in the vast majority of lead dysfunction cases.

- The pattern observed in this patient is highly suggestive of recent lead dysfunction with oversensing of very short cycles and false episodes of NSVT with rapid cycles; lead dysfunction can also be associated with impedance variations, although this often occurs later than oversensing of non-physiological signals.

- The LIA algorithm has been developed to generate an alert when lead dysfunction is suspected and to delay the onset of therapy by monitoring bipolar and integrated bipolar impedances, the frequency of episodes of non-sustained VT and the frequency of very short ventricular cycles; lead dysfunction is suspected if at least 2 of the following 3 criteria are met over the last 60 days: 1) the pacing impedance in one of the 2 polarities (bipolar and/or integrated bipolar) is 50% lower or 175% higher than a baseline value corresponding to the median of the previous 13 daily measurements; 2) the ventricular sensing integrity counter (short ventricular intervals ≤ 130ms) has incremented to at least 30 over a period of 3 consecutive days; 3) the device has detected 2 episodes of rapid non-sustained VT with an average RR interval over 5 beats of less than 220ms.

- When lead malfunction is suspected, the device transmits a specific telemedicine alert, an audible alert is emitted every 4 hours until the defibrillator is interrogated and the number of intervals required for detection is automatically extended to 30/40 to delay (but not prevent) the occurrence of inappropriate therapies.

11 telemedicine monitoring to avoid disasters

Patient

Man implanted with a triple-chamber defibrillator (Viva XT CRT-D), hospitalised for multiple electric shocks in the absence of prior symptoms.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	0	6	No	5	13-Mar-2014	16:34	:04:22	100/286	111/400	Active
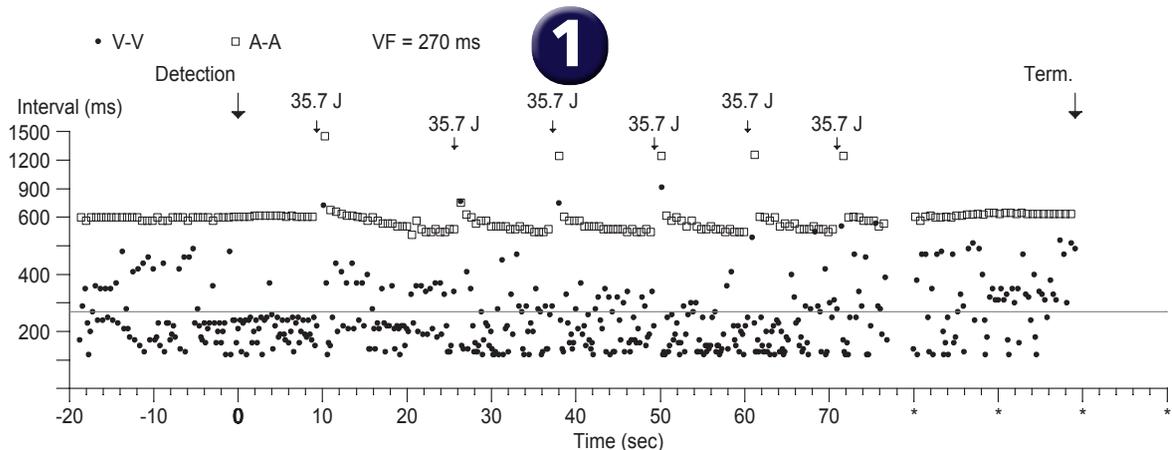
1 What do you think of this interval plot?

The plot shows a characteristic feature of lead dysfunction with a cloud of points (very high cycle-to-cycle variability) and very short ventricular cycles at the limit of the blanking value; 6 maximum electric shocks were delivered with no significant impact on the sensed ventricular rate.

35.7 J

VF
VF Rx 3 Defib

1250

35.7 J

VF
VF Rx 4 Defib

NT
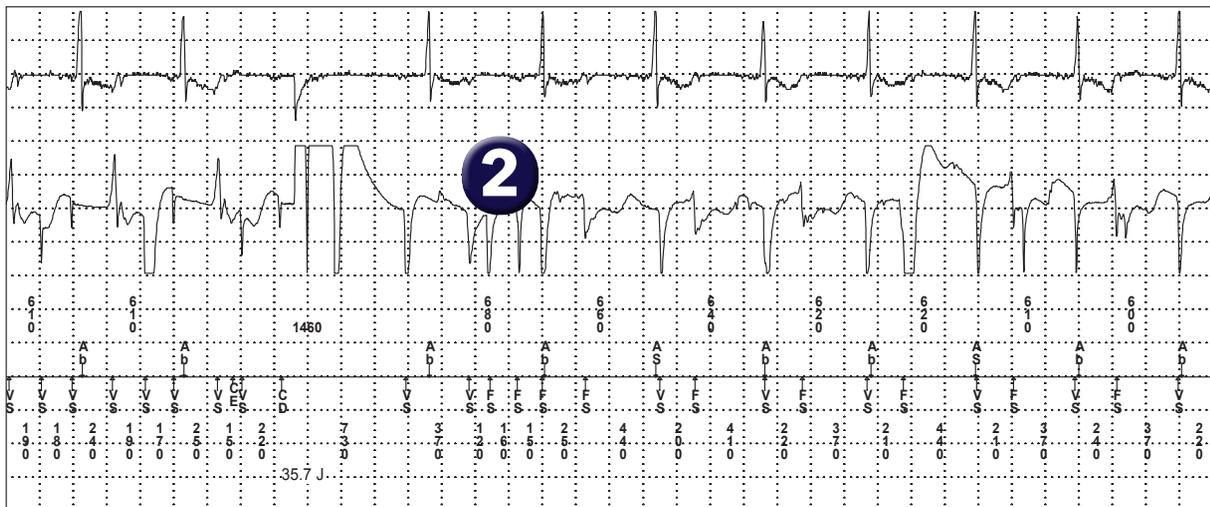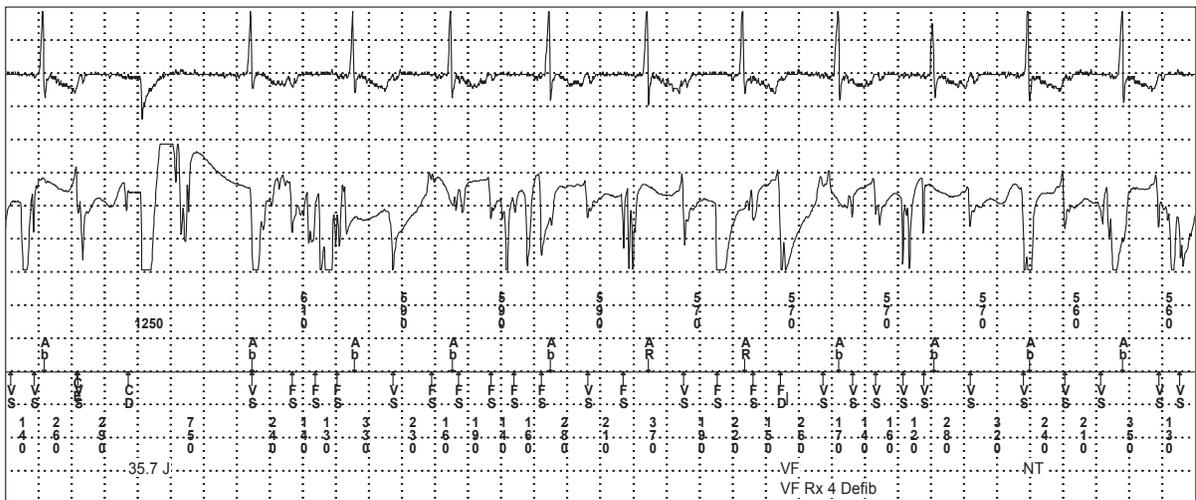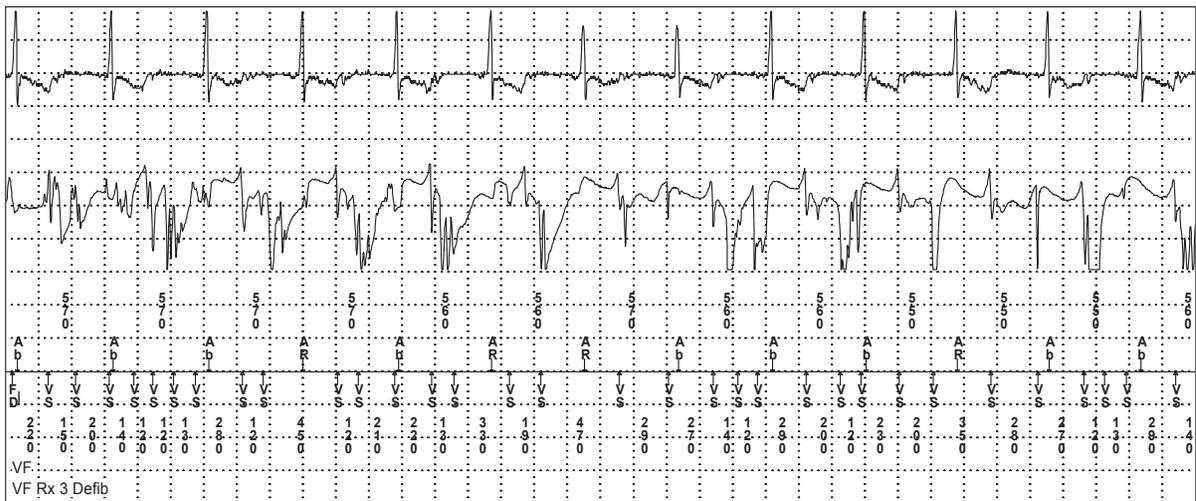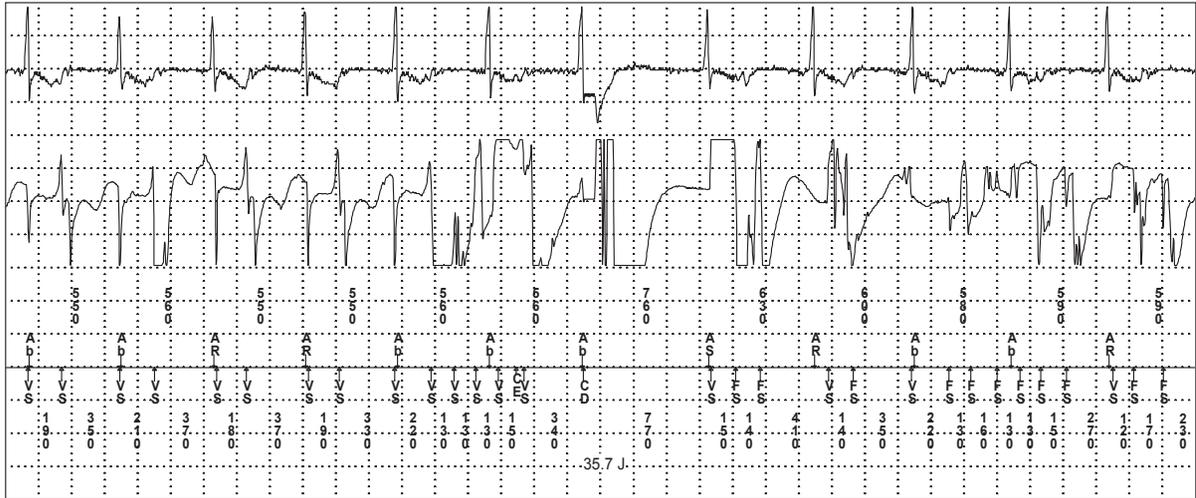
2 What do you think of the EGM?

The EGM is highly suggestive of lead dysfunction, with evidence of chaotic signals that vary in amplitude and frequency, with no relation to the QRS complexes. Some signals saturate the amplifiers and some cycles border on the programmed blanking interval.

RV Impedance

――――― Bipolar
------------ Tip to Coil

ohms
Lead Warning

>3000
2500
2000
1500
1000
500
0

③

Jan-13   Jun-13   Oct-13   05-Mar-14   19-Mar-14

Last 80 weeks (min/max/avg per week)   **Last 15 days**
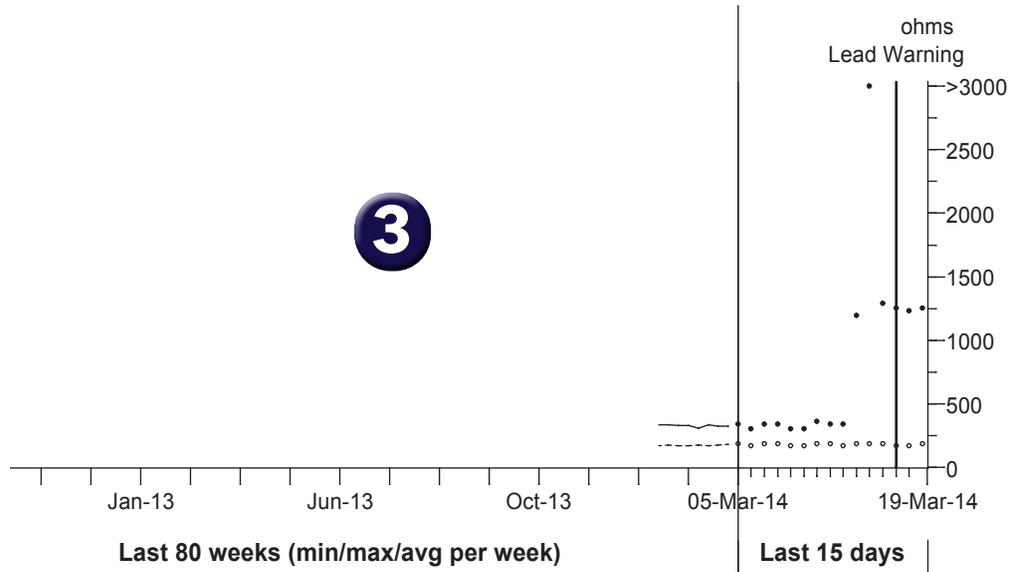
RV Threshold

Capture	Adaptive
Amplitude	5.00 V
Pulse Width	1.00 ms
Last Measured	High

x = High Threshold

V @ 0.40 ms

xxxxxx >2.5
2.0
1.5
1.0
0.5
0

④

Sep-12   Jan-13   Jun-13   Oct-13   05-Mar-14   19-Mar-14
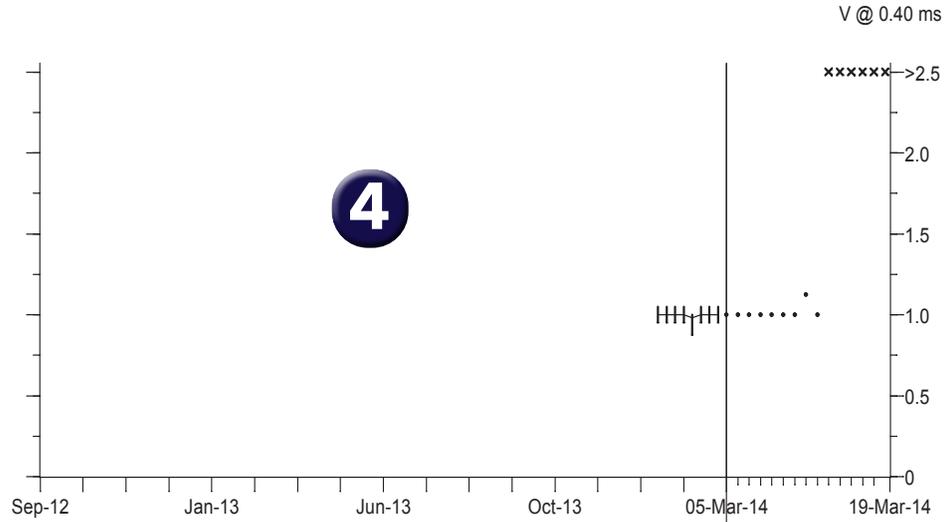
R-Wave Amplitude

Sensitivity	0.30 mV
Last Measured	6.6 mV

mV

>20
16
12
8
4
0

Sep-12   Jan-13   Jun-13   Oct-13   05-Mar-14   19-Mar-14

Last 80 weeks (min/max/avg per week)   **Last 15 days**
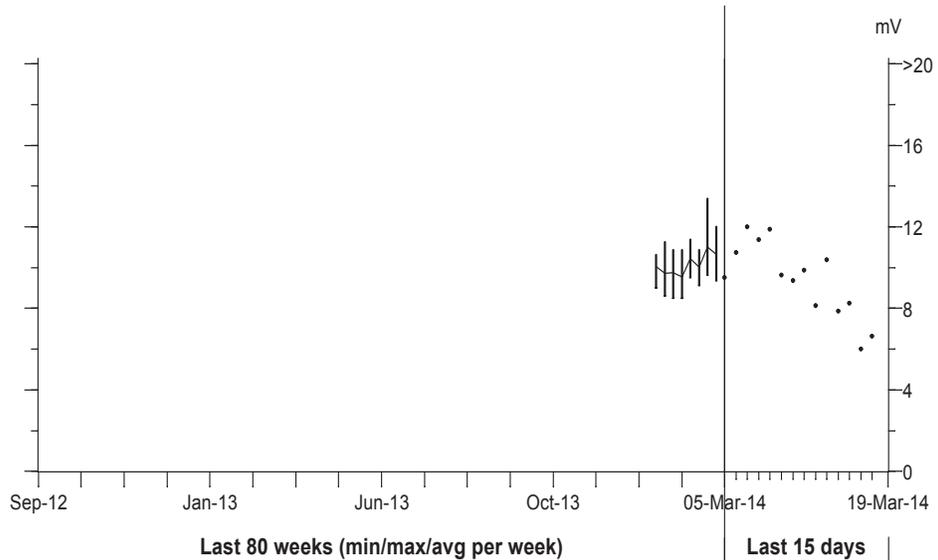
3 What do you think of the appearance of the impedance curves?

The impedance curve for bipolar stimulation (between the distal and proximal electrodes) shows a very clear break with normal values followed by a sharp increase to a measurement above 3000 Ohms; in contrast the impedance curve measured in integrated bipolar (between the distal electrode and the coil) returns normal values; this suggests the existence of a break in the proximal electrode.

4 What do you think of the appearance of the threshold and ventricular detection curves?

The right ventricular threshold curve shows an abrupt increase in measurements with a progressive decrease in R wave amplitude (from 10 to 5 mV).

Key messages

- This example illustrates the successive stages usually observed in «historical» lead dysfunction: firstly, the device's memory showed multiple episodes of non-sustained VT without any lead measurement anomalies; secondly, a clear break in the various impedance, threshold and right ventricular sensing curves was observed; in the absence of a diagnosis of lead dysfunction, the patient underwent the traumatic experience of receiving multiple electric shocks.

- This patient was not monitored by telemedicine, which prevented an early diagnosis before the shocks occurred; reducing the number of inappropriate shocks is a priority in the programming and monitoring of implanted patients; telemedicine has shown to be effective in this context, presently receiving a class I indication; it should therefore be offered systematically to all patients with a defibrillator.

- This type of episode also demonstrates the value of limiting the number of therapies delivered for a single episode, as the occurrence of successive inappropriate shocks is a traumatic ordeal for the patient.

12 the benefits of induction at the end of implantation

Patient

Patient implanted with a dual-chamber defibrillator with a Fidelis lead undergoing a box change (Evera XT DR); induction protocol at the end of the procedure.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	0	35J,35J	No	1	08-Dec-2015	16:30	:40	---/240	---/286	Active
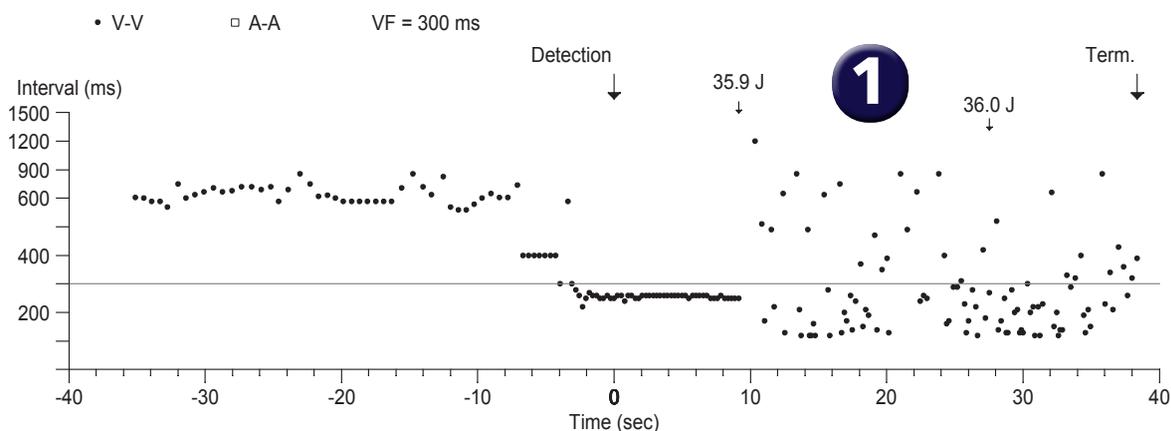
1 What do you think of this interval plot?

The plot initially shows an induction protocol with rapid pacing burst; the fact that the low-amplitude electric shock is delivered on the T wave is not indicated on the graph; induction of a probable ventricular arrhythmia detected in the VF zone (appearance compatible with a real ventricular arrhythmia); the first shock delivered (35 Joules) significantly alters the ventricular cycles, with evidence of a cloud of points (very short cycles and longer cycles with great variability); the second shock does not alter the appearance of the ventricular cycles.

EGM1: Atip to Aring

(0.1 mV)

2

EGM3: RVtip to RVring

(1 mV)

A-A (ms):

Markers:

| | | T | T | T | T | T | T | T | T | C | | V | V | F | F | F | |
| | | P | P | P | P | P | P | P | P | D | | S | S | S | S | S | |

V-V (ms):

4	4	4	4	4	4	4	3	5	3	2	2	2
0	0	0	0	0	0	0	3	9	3	8	6	2	2
0	0	0	0	0	0	0	0	0	0	0	0	0	5	5
													0	0

3

| F | F | F | F | F | F | F | F | V | V | V | V | V | V | V | V | V | V | V | V | V | V | V | V | V | V | V |
| S | S | S | S | S | S | S | D | S | S | S | S | S | S | S | S | S | S | S | S | S | S | S | S | S | S | S |

2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
7	6	6	5	5	6	5	6	6	4	6	6	5	6	6	6	6	6	6	6	6	6	6
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

VF:
VF Rx 1 Defib

4

| V | V | V | V | V | V | V | V | V | V | V | V | V | C | V | C | | | | T | V | F | V | F |
| S | S | S | S | S | S | S | S | S | S | S | E | S | E | S | D | | | | P | S | S | S | S |

2	2	2	2	2	2	2	2	2	2	2	2	2					5	1	4	2	6
5	6	6	6	6	6	5	5	6	5	5	5	5	1200			1	7	9	2	5
0	0	0	0	0	0	0	0	0	0	0	0	0				0	0	0	0	0

35.9 J

2 What type of procedure is involved?

The EGM shows rapid ventricular pacing followed by a low-amplitude shock delivered on the T wave (in the vulnerable period) due to an induction protocol at the end of implantation to check for correct defibrillator function.

155

③ What is the effect of the first low output shock?

The electric shock induces rapid ventricular tachycardia, which is detected in the VF zone.

④ What is the effect of the second high output shock?

The electric shock terminates the ventricular arrhythmia but is followed by the over-detection of anarchic signals with saturation of the amplifiers, suggesting a diagnosis of lead dysfunction.

Key messages

- This plot shows the value of inducing ventricular arrhythmia when changing leads, particularly when the patient is implanted with a lead known to have an increased rate of dysfunction.

- Lead fracture was unmasked in this patient following detection of an episode of induced VF and the delivery of an electric shock; the electric shock delivered sometimes stretches a lead which had already been stretched and weakened beforehand and causes a definitive fracture; the stimulation impedances were strictly normal prior to this episode and no episode of oversensing had previously been recorded in the device memory; therefore there was no warning sign of lead dysfunction and no other indication for this patient to have an induction protocol performed when the box was changed.

- This young patient had the faulty lead removed and a new ipsilateral lead implanted.

13 use of an algorithm to avoid inappropriate therapies

Patient

Patient with dilated cardiomyopathy implanted with a single-chamber defibrillator (Protecta XT VR).

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
V. Oversensing-Noise				20	20-Mar-2012	18:06	:20	273	300	Rest

1

• V-V   VF = 320 ms   FVT = 260 ms   VT = 400 ms

VT/VF Detection Withheld   Term.

2

Interval (ms)

1500
1200
900
600

400

200

-25   -20   -15   -10   -5   0   -10   -5   0

Time (sec)
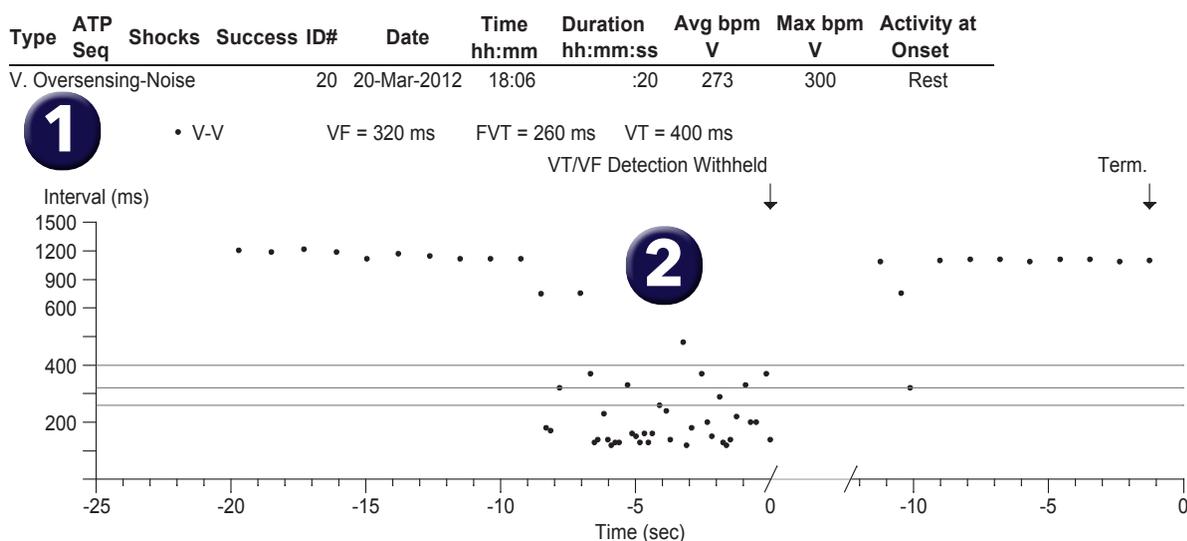
1 What is the diagnosis made by the system?

The system classified this episode as oversensing of noise.

2 What diagnosis is suggested by the interval plot?

The plot shows a characteristic cloud of points with significant cycle-to-cycle variability and very short ventricular cycles at the limit of the programmed blanking value, suggesting the diagnosis of oversensing.

EGM1: RVtip to RVring

(1 mV)

EGM2: Can to RVcoil

(1 mV)

Markers

V-V (ms):

Waveform suspended
for 10 sec

③ What is your diagnosis?

The EGM reveals chaotic cycles in the bipolar channel with marked variation in amplitude and frequency, no relationship to the QRS complexes, with some signals saturating the amplifiers and some cycles bordering on the programmed blanking; there is much less or no oversensing on the shock channel.

④ What is the explanation for the inhibition of therapies?

The VF counter is full but no therapy is delivered, the device having diagnosed oversensing due to lead malfunction after implementation of the noise algorithm (N for noise).

Key messages

- The lack of long-term reliability of defibrillation leads is one of the main limitations of implantable devices and one of the most difficult challenges for the manufacturers involved.

- Medtronic™ devices are equipped with 2 complementary algorithms specifically dedicated to the diagnosis of lead dysfunction and the prevention of inappropriate shocks: the LIA and the RV Lead noise discrimination algorithm.

- The principle of this second algorithm is to analyse the EGM tracings, identify an oversensing episode (a non-physiological episode that does not correspond to true arrhythmia) and inhibit therapies.

- The identification of electrograms characteristic of lead fracture is based on a comparison of the amplitude (peak to peak) of the signals recorded in the shock channel (far-field) and the signals recorded in the sensing channel (near-field); conceptually, this is based on the fact that during oversensing, signals may be present on the bipolar channel but absent on the shock channel, unlike a true arrhythmia episode where fast signals are detected simultaneously on both channels.

- The amplitude of 12 consecutive signals is analysed over a sliding window using a counter; when the number of intervals required to detect VT or VF has

159

been completed, if 3 of the 12 sequences (amplitude comparison at far-field and near-field channel level) are classified as «noise», detection is interrupted, therapies are not delivered and a «noise on RV lead» alert is triggered (an audible alert is emitted by the device every 4 hours until the defibrillator is interrogated; a telemedicine alert is also transmitted if this specific alert has been programmed).

• This algorithm can be set to OFF, ON or ON + Timeout; in the latter case, a time limit is programmed; if noise oversensing continues beyond this time (15 seconds to 2 minutes), therapies are delivered despite the diagnosis made by the device.

• In practice, LIA enables a much earlier diagnosis of lead dysfunction than this second algorithm; in fact, the LIA issues an alert in the presence of short cycles and episodes of non-sustained VT, whereas the noise algorithm only intervenes if the initial counter is filled (30/40) and therefore only during a sustained episode of oversensing. This second algorithm is therefore only useful if, despite the LIA alerts, no action has been taken, or if the very first episode of oversensing is sustained long enough to fill the initial counters (a relatively rare occurrence).

• Therefore LIA most often enables an early diagnosis; it delays therapies but does not inhibit them and generates an alert, whereas the noise algorithm often results in a later diagnosis but inhibits therapies.

14 a characteristic feature on the EGM

Patient

Male implanted with a triple-chamber defibrillator (Viva XT CRT-D) receiving an electric shock in a particular context.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	0	35J	Yes	39	12-Dec-2018	14:28	:19	182/375	182/---	Rest
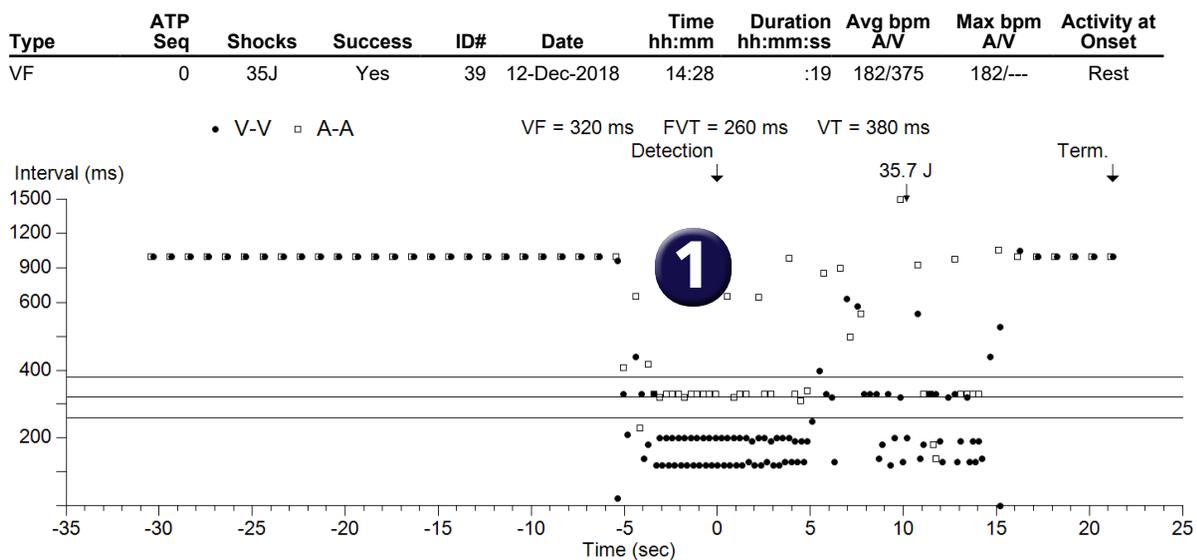
1 What is shown on the interval plot?

The plot shows a railroad track appearance on the ventricular channel in the VF zone; the VF counter is implemented and the device delivers an electric shock.
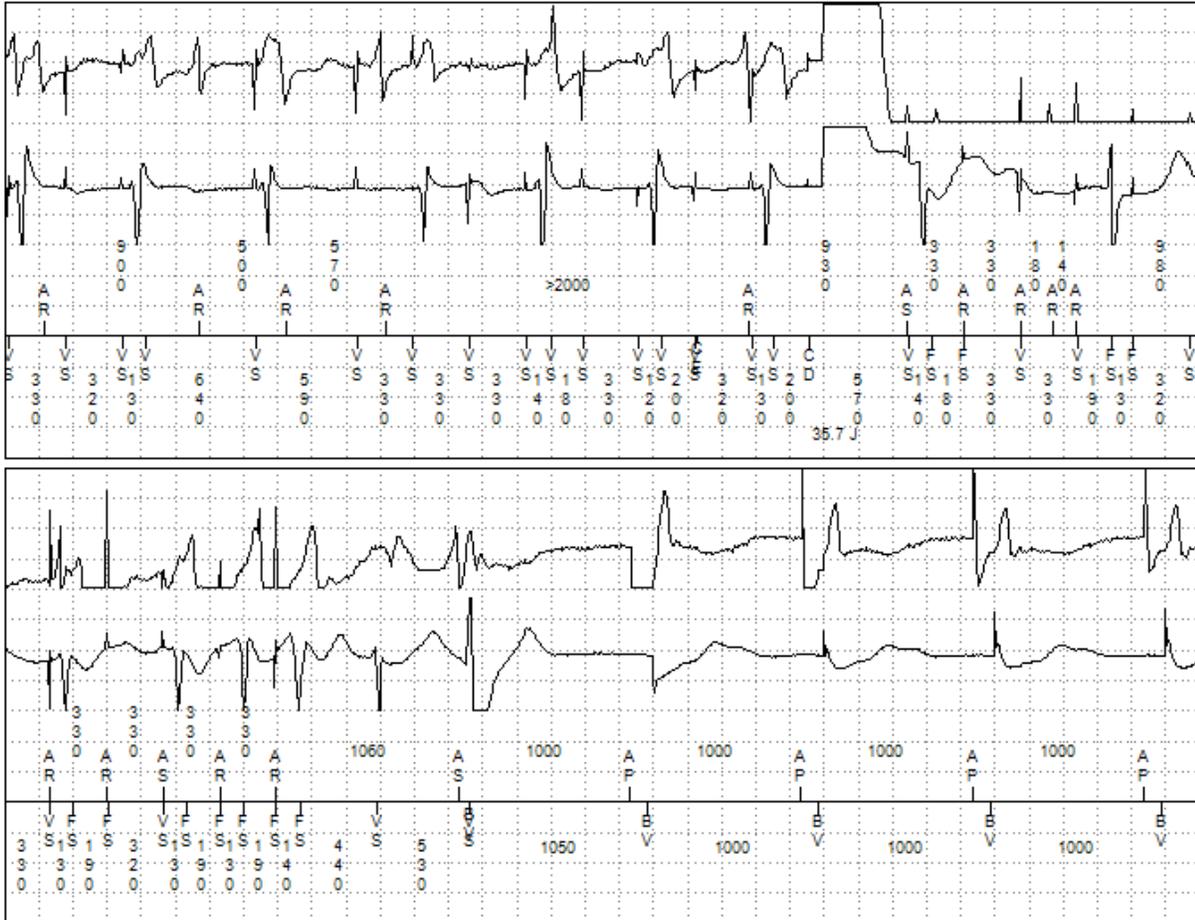
2 What is your diagnosis of the EGM?

The ventricular EGM shows cycles detected in the VF zone alternating between a first acute signal, also visualised on the atrial channel and resembling a pacing spike, and a second signal that may correspond to ventricular depolarisation; the diagnosis evoked by this observation is the presence of external rapid ventricular pacing with double counting (pacing artefact + ventricular depolarisation) leading to the delivery of an electric shock.

③ What is missing from the diagnosis?

The missing element here is the context in which this episode occurred; in this patient, the electric shock was delivered during a TAVI implantation procedure at the time of rapid external pacing.

Key messages

- In the presence of a problem of oversensing, knowledge of the context sometimes enables the diagnosis to be made (use of a poorly insulated household electrical product, etc.); in this case the diagnosis is obvious when we know that the shock was delivered during a TAVI implantation procedure.

- Since the first percutaneous aortic valve implantation in 2002, the indications for TAVI (transcatheter aortic valve implantation) have evolved considerably, with a steady increase in the number of procedures performed worldwide.

- During the TAVI implantation procedure, rapid ventricular pacing is usually delivered to induce severe transient hypotension and reduce the risk of embolisation of the prosthesis.

- The features of oversensing observed in this context is characteristic.

- During the TAVI implantation procedure, the implantable defibrillator must be temporarily deprogrammed to avoid the occurrence of inappropriate therapies (detection of pacing artefact, rapid ventricular rhythm, etc.) as in this example.

VS

TS TS TS TS TS TS TS TS

430 420 400 420 420 430 430 430

Chapter 4

Discrimination

1 discriminators available on a single-chamber defibrillator

Patient

Male with ischaemic cardiomyopathy implanted with a single-chamber defibrillator (Virtuoso VR) presenting with multiple episodes of VT.
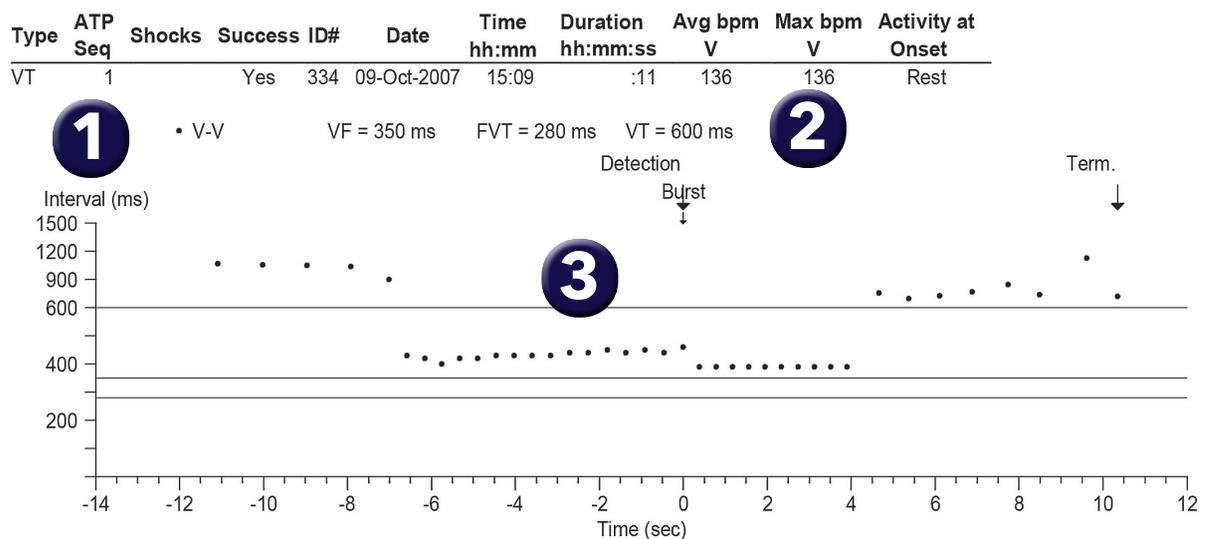
Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VT	1		Yes	334	09-Oct-2007	15:09	:11	136	136	Rest

• V-V   VF = 350 ms   FVT = 280 ms   VT = 600 ms

Detection Burst   Term.

Interval (ms)

1 What is the diagnosis made by the defibrillator for this episode?

This episode was classified as VT by the device.

2 How many detection zones are programmed?

Three detection zones have been programmed with a VT zone of 600 to 350 ms.

3 What diagnosis does the interval plot suggest?

The graph shows an initially stable rhythm of around 60 bpm with sudden acceleration and cycles recorded in the VT zone; a burst is delivered with normalisation of the heart rate.

EGM1: RVtip to RVring
:(1 mV)

EGM2: Can to RVcoil
:(1 mV)

Markers.

V-V (ms):

V S	V S	T S	V S	V S
1070	1060	1050	1040	9 0 0

5 **6**

V S	T S	T S	T S	T S	T S	T S	T S	T S	T S	T S	T S	T S	T S	T S	T D
4 3 0	4 2 0	4 0 0	4 2 0	4 2 0	4 3 0	4 3 0	4 3 0	4 3 0	4 2 0	4 4 0	4 4 0	4 5 0	4 4 0	4 5 0	4 4 0	4 6 0

V V

7 **8**

T P	T P	T P	T P	T P	T P	T P	T P	T P	T P	V S	V S	V S	V S
3 9 0	3 9 0	3 9 0	3 9 0	3 9 0	3 9 0	3 9 0	3 9 0	3 9 0	7 6 0	7 0 0	7 3 0	7 7 0

T.
T Rx 1 Burst
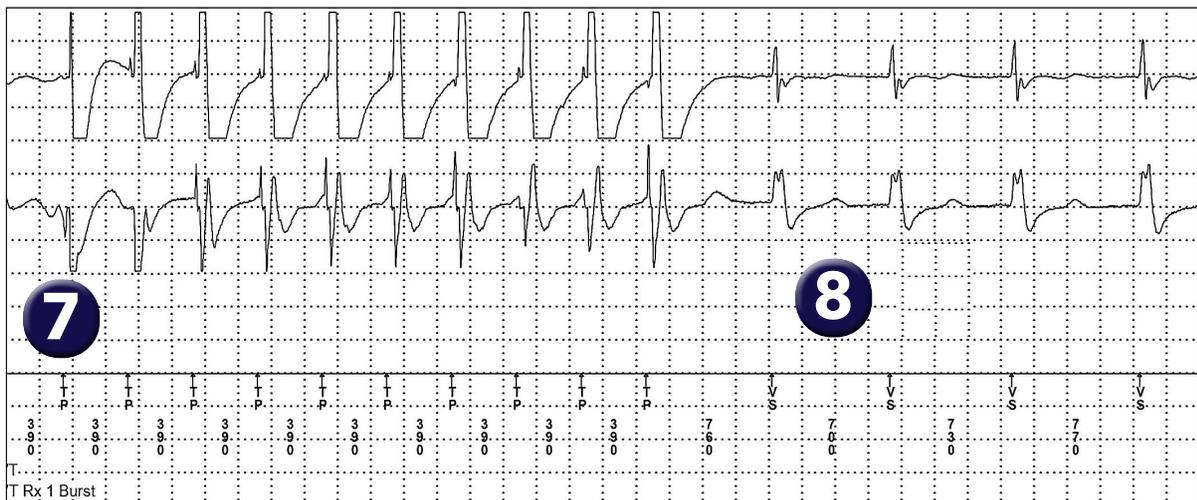
Episode Summary

Initial Type	VT (spontaneous)
Duration	11 sec
V. Max Rate	136 bpm
V. Median	136 bpm (440 ms)
V. Stability	10 ms - 20 ms
Activity at onset	Rest, Sensor = 53 bpm
Last Therapy	VT Rx1: Burst, Successful

Initial VT/VF Detection Withheld By

None

Therapies

Therapies	Delivered	Charge	Ohms	Energy
VT Rx 1 Burst	Seq 1			
|				
Termination				

Wavelet Measurements Prior to Initial VT/VF Detection

Wavelet Result: VT/VF
Template Status: Inconsistent with intrinsic rhythm

-8.	No Match	31 %
-7.	No Match	31 %
-6.	No Match	34 %
-5.	No Match	31 %
-4.	No Match	28 %
-3.	No Match	31 %
-2.	No Match	31 %
-1.	No Match	28 %
0.	Detection	

Onset Criterion Result

Sudden Onset - VT.

Parameter Settings

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	12/16	9/12	350 ms (171 bpm)
FVT	via VF			280 ms (214 bpm)
VT	On	16	12	600 ms (100 bpm)
Monitor	Off	20		

Wavelet

Wavelet	Monitor, Match = 70 %
Template	06-Oct-2007, Auto = On
SVT V. Limit	320 ms

Other Enhancements

Stability	40 ms
Onset	On (81%)
High Rate Timeout	Off

4

EGM

EGM	EGM1	EGM2	Sensitivity	
Source	RVtip to RVring	Can to RVcoil	RV	0.45 mV
Range	+/- 8 mV	+/- 8 mV		

④ How many discrimination parameters are programmed?

The 3 discrimination criteria available in a single-chamber defibrillator are programmed: sudden onset (81%), stability (40 ms) and Wavelet (70% similarity); Wavelet is programmed on Monitor (data are recorded but not used for the decision).

⑤ How do you rate the start of the episode?

The onset is abrupt, with ventricular cycles initially around 1000 ms, followed by cycles around 400 ms.

⑥ How do you describe the stability of the tachycardia?

The tachycardia is monomorphic and visually regular; the intervals detected by the device oscillate between 400 and 450 ms; even when the tachycardia appears visually regular, there may be small variations in the duration of the intervals detected, as the time at which the device detects the R wave may vary with respiration.

⑦ How do you analyse the morphology of QRS complexes during tachycardia?

The shock channel (between the box and the right ventricular coil) is used to record a tracing similar to an ECG lead; on this channel, the change in morphology is obvious between the initial tracing and the tracing in tachycardia.

⑧ What is the effect of the burst?

The burst is effective and terminates the tachycardia.

Key messages

- The initial detection of an arrhythmia episode is based on heart rate and duration criteria; heart rate is essential but too simplistic to differentiate between ventricular rhythm disorders and supra-ventricular arrhythmias; as a standalone criterion, heart rate provides a sensitivity of 100% (all VT episodes exceeding this rate are detected) but specificity of less than 60% (all SVT episodes exceeding this rate are also detected). The improvement in specificity is therefore based on discrimination, which is the ability of a defibrillator to identify a supra-ventricular or ventricular origin of an episode of tachycardia, based on the characteristics of the arrhythmia detected.

- The detection of an arrhythmia episode, whether supra-ventricular or ventricular, triggers the storage of an endocardial EGM that can be accessed when the defibrillator is interrogated, enabling critical analysis of the defibrillator's diagnostic conclusions and possible reprogramming in the event of a tachycardia classification error.

- The performance of a discrimination algorithm is assessed based on its sensitivity (ability to correctly diagnose a VT; this should be as close as possible to 100%; a sensitivity of 95% means that 5% of VTs will be wrongly diagnosed as SVT) and its specificity (ability to inhibit therapies during an episode of SVT; this should be as high as possible without altering sensitivity).

- In single-chamber defibrillators, 3 criteria can be programmed to discriminate the origin of arrhythmias: Sudden Onset, Stability and Wavelet.

- Each criterion can be programmed to 'On', 'Off' or 'Monitor'; Monitor mode allows the performance of a criterion to be assessed without it being taken into account for discrimination; if all the criteria are set to 'Monitor' or 'Off', discrimination is inactivated and therapy is delivered regardless of the origin of the tachycardia; depending on the programming, each parameter can be made more or less sensitive, or more or less specific.

- When the 3 parameters are set to 'On', the diagnosis of VT requires a sudden onset (validated at the start of the episode), stability of the ventricular cy-

cles (throughout the tachycardia for initial detection and for redetection) and a change in the morphology of the QRS complexes (assessed over the last 8 cycles before the counter is filled); therefore all 3 criteria must indicate a diagnosis of VT.

- As indicated on the plot, the episode dates back to 2007 and was therefore recorded on an old defibrillator platform (Virtuoso); although the programmable parameters (number of zones, discriminators, etc.) available on defibrillator platforms have changed relatively little since 2007, the way defibrillators are programmed has changed considerably; it is now very rare to program therapy zones for heart rates as low as 100 bpm; similarly, the 3 discriminators available on a single-chamber defibrillator are rarely simultaneously programmed 'on' in the first instance.

② sudden onset criterion and sinus tachycardia

Patient

45-year-old male implanted with a single-chamber defibrillator (Evera MRI XT VR) for hypertrophic cardiomyopathy with episodes of VT at 160 beats/minute.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
SVT-Onset				444	01-Jul-2018	09:03	:36	136	140	Active
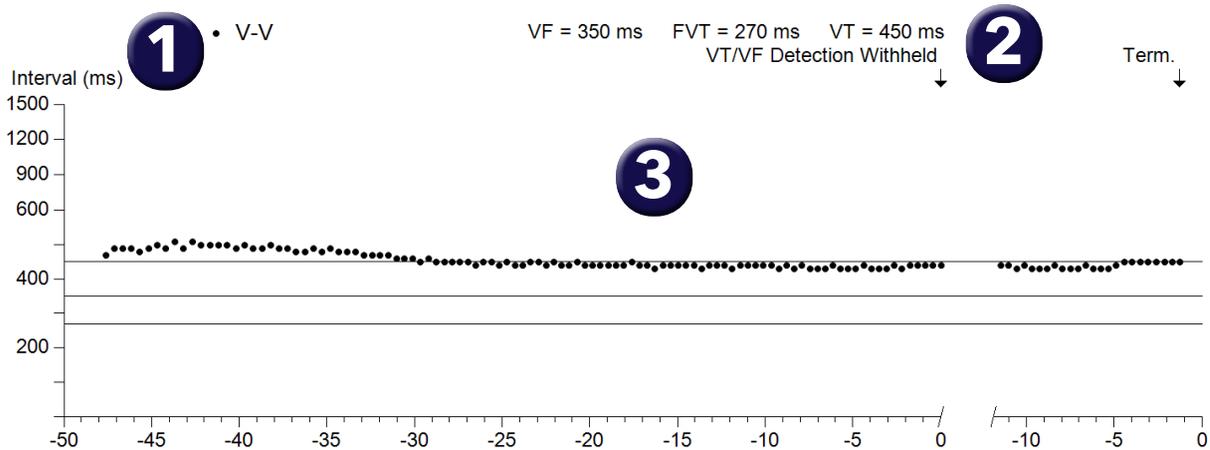
① What is the diagnosis made by the defibrillator for this episode?

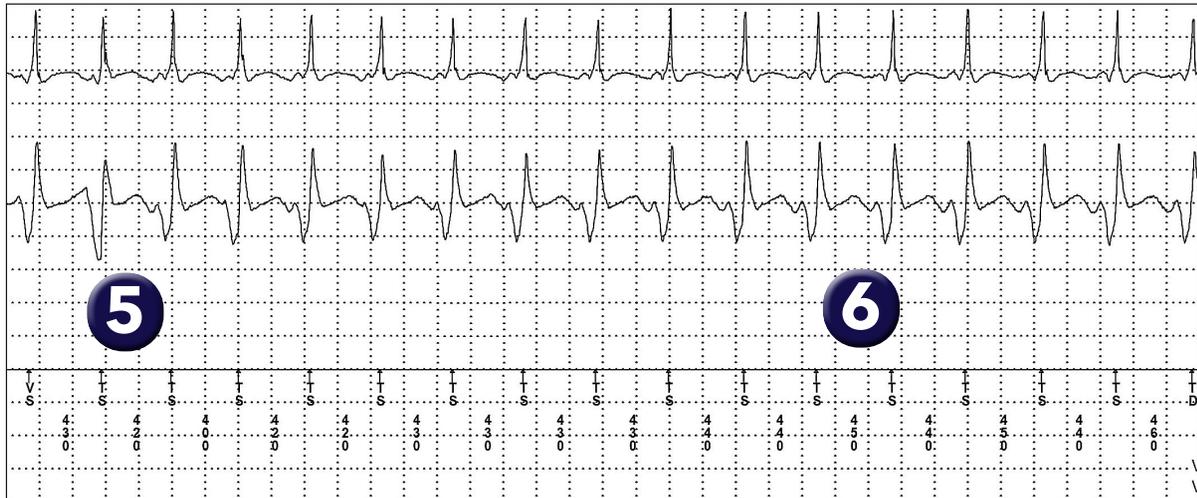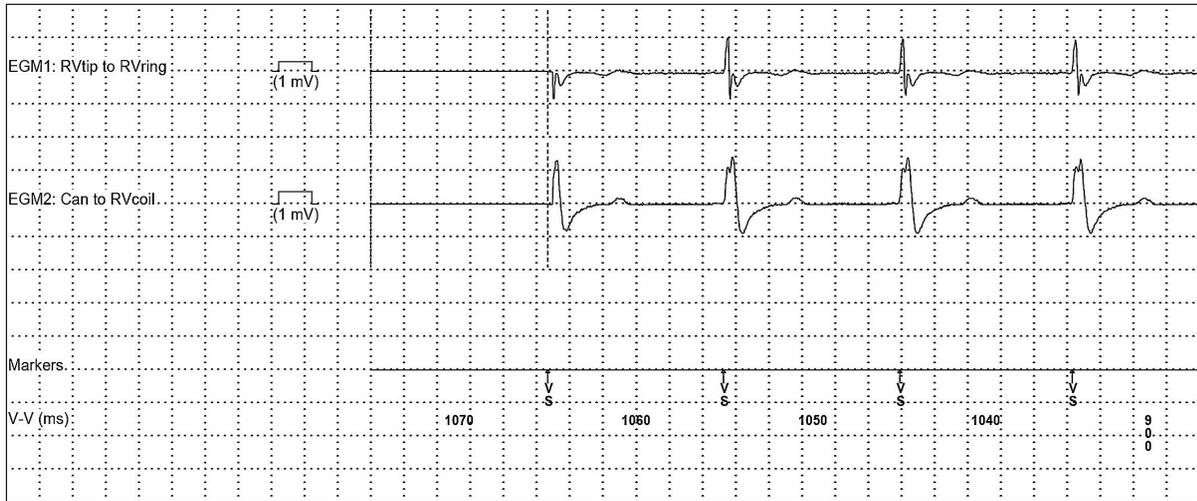This episode was classified as SVT by based on the sudden onset criterion.

② How many detection zones are programmed?

Three detection zones have been programmed with a VT zone of 450 to 350 ms.

③ What diagnosis does the interval plot suggest?

The graph shows an appearance compatible with a sinus tachycardia oscillating around the lower limit of the VT zone; the tachycardia appears regular with progressive acceleration and then deceleration at the end of the episode.

EGM1: RVtip to RVring (1 mV)

EGM2: Can to RVcoil (1 mV)

Markers

V-V Interval (ms)

Reset: Onset   Reset: Onset   Reset: Onset   Reset: Onset

⑤

Reset: Onset   Reset: Onset

Waveform su for 30 sec.

Episode Summary

Initial Type	SVT - Onset (spontaneous)	
Duration	36 sec	
V. Max Rate	140 bpm	
V. Median	136 bpm (440 ms)	
Activity at onset	Active, Sensor = 111 bpm	

Other Criteria Triggered

Onset

Parameter Settings

	Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	350 ms (171 bpm)
FVT	via VF			270 ms (222 bpm)
VT	On	40	12	450 ms (133 bpm)
Monitor	Off	32		

Wavelet

Wavelet	On, Match = 70%
Template	
SVT V. Limit	

Other Enhancements

Stability	Off
Onset	On (81%)
High Rate Timeout	
VF Zone Only	Off
All Zones	Off
TWave	On
RV Lead Noise	On+Timeout
Timeout	0.75 min

176

④ How many discrimination parameters are programmed?

Two discrimination criteria are programmed: sudden onset (81%) and Wavelet (70% similarity).

⑤ What does the term 'Reset Onset' mean?

The QRS complexes visualised on the shock channel are narrow and compatible with supra-ventricular tachycardia; the sudden onset criterion is not fulfilled, the acceleration and re-entry into the VT zone being very gradual; as long as the sudden onset criterion is not fulfilled, the sudden onset algorithm is reset and Wavelet is not analysed.

Key messages

- The patients who benefit most from discrimination are those where the heart rates of ventricular tachycardias and supraventricular tachycardias overlap (patients with slow VT, patients likely to have rapid AF, young patients with rapid sinus tachycardia on exertion).

- The percentage of inappropriate therapies has fallen considerably since the very first defibrillator studies and now stands at between 1 and 5% per annum. The reasons for this significant reduction are multifactorial (programming of longer detection times, programming of detection zones for tachycardias > 187 beats/minute in the first instance, programming of discrimination algorithms); it is therefore difficult to precisely isolate the effect of programming discrimination algorithms.

- This episode corresponds to a sinus tachycardia correctly discriminated by the defibrillator; typically, in sinus tachycardia, 2 out of 3 criteria indicate SVT; in fact, there is usually an absence of sudden onset, a stable rhythm and a similar morphology; in this example, stability had not been programmed.

- The sudden onset criterion is based on the principle that a sinus tachycardia starts gradually whereas a ventricular tachycardia starts abruptly; a gradually accelerating tachycardia (sudden onset criterion not met) is not considered VT by the device and is therefore not treated.

- In practice, the device compares the average duration of 4 consecutive cycles with the average duration of the 4 preceding cycles; a programmable minimum percentage of acceleration between these 2 series of 4 cycles defines a sudden onset; as long as the onset is considered to be gradual, even if the cycle length corresponds to the VT zone, detection is delayed, the event is marked VS and the annotation «Reset Onset» appears on the trace.

- The sudden start criterion applies - for VT and FVT via VT zones but not for VF or FVT via VF zones, - during the initial detection phase, but not during the re-detection phase.

- The sudden onset criterion may be misleading in certain scenarios and lead to an erroneous diagnosis in 2 types of patients: 1) patients with VT during exertion (ischaemic cardiomyopathy, hypertrophic cardiomyopathy, long QT or right ventricular dysplasia) where there may be no clear break between the rate of the sinus tachycardia preceding the VT and the VT rate; 2) patients where the VT rate oscillates around the lower limit of the VT zone.

- The stability criterion is based on the principle that atrio-ventricular conduction during an episode of conducted atrial fibrillation is generally irregular and gives rise to an unstable ventricular rate, whereas an episode of ventricular tachycardia is most often associated with a stable ventricular rate; an irregular tachycardia (stability criterion not met) is not considered VT by the device and is therefore not treated.

- In practice, stability analysis begins when the VT counter reaches at least 3; the device compares the ventricular cycle length with the 3 previous cycle lengths; when the difference between a ventricular cycle and one of the 3 previous cycle lengths is greater than the programmed stability interval, the rhythm is deemed unstable, the cycle is classified as VS, the VT counter is reset to 0 and the annotation «Reset: Stability» appears on the trace.

- The stability criterion applies - for VT and FVT via VT zones but not for VF or FVT via VF zones (same as for sudden onset) - during the initial detection phase and also during the redetection phase (different to sudden onset); this is the only discrimination criterion that applies during redetection.

- In theory, the stability criterion can be used to differentiate between atrial fibrillation (irregular) and ventricular tachycardia (regular); however, this parameter cannot be used to distinguish between ventricular tachycardia and sinus tachycardia or atrial tachycardia/flutter, where the ventricular rhythm is usually regular.

- The stability criterion may be misleading in certain instances and may lead to an erroneous diagnosis in patients 1) in rapid AF with a rate in excess of 170 beats/minute where the rhythm is generally stable, 2) in certain patients where the onset of VT is accompanied by an irregular ventricular rhythm with regularisation at a later stage.

- Discrimination by stability analysis should not be used for tachycardias >180-200bpm to avoid the risk of not treating polymorphic VT and VF.

③ choice of discriminators in a single-chamber defibrillator

Patient

Male implanted with a single-chamber defibrillator (Visia AF XT VR) for ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VT	1		Yes	10	12-Aug-2021	01:59	:18	188	188	Rest

• V-V   VF = 310 ms   FVT = 260 ms   VT = 370 ms

① What was the diagnosis made by the defibrillator for this episode?

This episode was clasified VT by the device.

② How many detection zones are programmed?

Three detection zones have been programmed with a VT zone of 370 to 310 ms.

③ What diagnosis does the interval plot suggest?

The graph shows an initially stable rhythm of around 60 bpm with sudden acceleration and cycles recorded in the VT zone; a burst is delivered with normalisation of the heart rate.

EGM1: RVtip to RVring

(1 mV)

EGM2: Can to RVcoil

(1 mV)

Markers

V-V Interval (ms):

V
S

V
S
9
5
0

V
S

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VT
VT Rx 1 Burst

Episode Summary

Initial Type	VT (spontaneous)
Duration	18 sec
V. Max Rate	188 bpm
V. Median	188 bpm (320 ms)
V. Stability	0 ms - 0 ms
Activity at onset	Rest, Sensor = 40 bpm
Last Therapy	VT Rx1: Burst, Successful

Initial VT/VF Detection Withheld By

None

Therapies	Delivered	Charge	Ohms	Energy
VT Rx 1 Burst	Seq 1			

|
Termination

Wavelet Measurements Prior to Initial VT/VF Detection

Wavelet Result:	VT/VF
Template Status:	OK

-8.	No Match	0 %
-7.	No Match	0 %
-6.	No Match	0 %
-5.	No Match	0 %
-4.	No Match	0 %
-3.	No Match	0 %
-2.	No Match	0 %
-1.	No Match	0 %
0.	Detection	

Parameter Settings | **Initial** | **Redetect** | **V. Interval (Rate)**

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	310 ms (194 bpm)
FVT	via VF			260 ms (231 bpm)
VT	On	48	12	370 ms (162 bpm)
Monitor	Off	32		

Wavelet

Wavelet	On, Match = 70%
Template	10-Jul-2021, Auto = On
SVT V. Limit	260 ms

Other Enhancements

Stability	Off
Onset	Off
High Rate Timeout	
VF Zone Only	Off
All Zones	Off
TWave	On
RV Lead Noise	On

④

Polarity | **RV**

Polarity	RV
Pace Polarity	Bipolar
Sense Polarity	Bipolar

EGM | **Source** | **Range**

EGM	Source	Range
EGM1	RVtip to RVring	+/- 8 mV
EGM2 (Wavelet)	Can to RVcoil	+/- 12 mV

Sensitivity

RV	0.3 mV

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VT	1		Yes	10	12-Aug-2021	01:59	:18	188	188	Rest

No Match 0 %   No Match 0 %   No Match 0 %   No Match 0 %
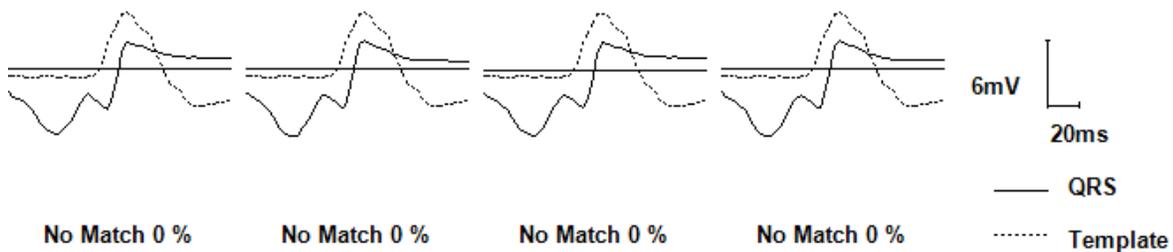
6mV
20ms
—— QRS
······ Template

No Match 0 %   No Match 0 %   No Match 0 %   No Match 0 %

⑦

4 How many discrimination parameters are programmed?

Wavelet is the only discrimination criterion programmed (70% similarity); the stability and sudden onset criteria are set to 'Off'.

5 How do you analyse the EGM in tachycardia?

This is a regular, monomorphic tachycardia with wide QRS (shock channel), with a different morphology to the EGM after tachycardia (morphology following the effective burst).

6 What therapy is delivered?

The VT counter is completed after 48 cycles classified as VT; the discrimination criterion indicates a diagnosis of VT and a burst is delivered; this terminates the tachycardia.

7 What do you think of the Wavelet results?

The appearance of Wavelet is clearly different from the reference morphology, with similarity percentages of 0% for the 8 ventricular complexes analysed, leading to a diagnosis of VT.

Key messages

- In this patient, discrimination was based exclusively on Wavelet; all the QRS complexes analysed were morphologically very different from the reference, the percentage match was very low (0%) and the episode was classified as VT, with a burst was used to interrupt the tachycardia.

- Wavelet-based discrimination is based on the principle that a ventricular complex conducted during supraventricular tachycardia most often has the same morphology as complexes recorded in the absence of tachycardia; a tachycardia with ventricular complexes of similar morphology to that of a reference complex recorded in sinus rhythm is not considered to be VT by the device and is therefore not treated.

- In practice, the device compares the morphology of the 8 QRS complexes preceding detection of the tachycardia with a reference morphology; if at least 6 of the last 8 complexes differ from the reference morphology, the device diagnoses an episode of VT; conversely, if at least 3 complexes are judged to be similar, the device diagnoses an episode of SVT and the VT counter is reset to 0; the similarity threshold is programmable (40, 43, …, 70, …, 97%).

- The device uses EGM2 to define the reference and analyse the morphology during tachycardia; collection of the reference signal is an essential stage in the correct operation of this parameter and can be carried out at the time of each interrogation or automatically and repeatedly by the device; to create the reference complex, the device collects 6 complexes in «normal sinus rhythm» and calculates a first average reference complex followed by an additional complex every 10 seconds for 700 seconds; with automatic collection switched 'On' the quality of the reference signal is confirmed with a comparison between the reference complex and a complex collected every 17 minutes.

4 single-chamber defibrillator and new recommendations

Patient

Male implanted with a single-chamber defibrillator (Visia AF XT VR) for primary prevention of ischaemic cardiomyopathy.
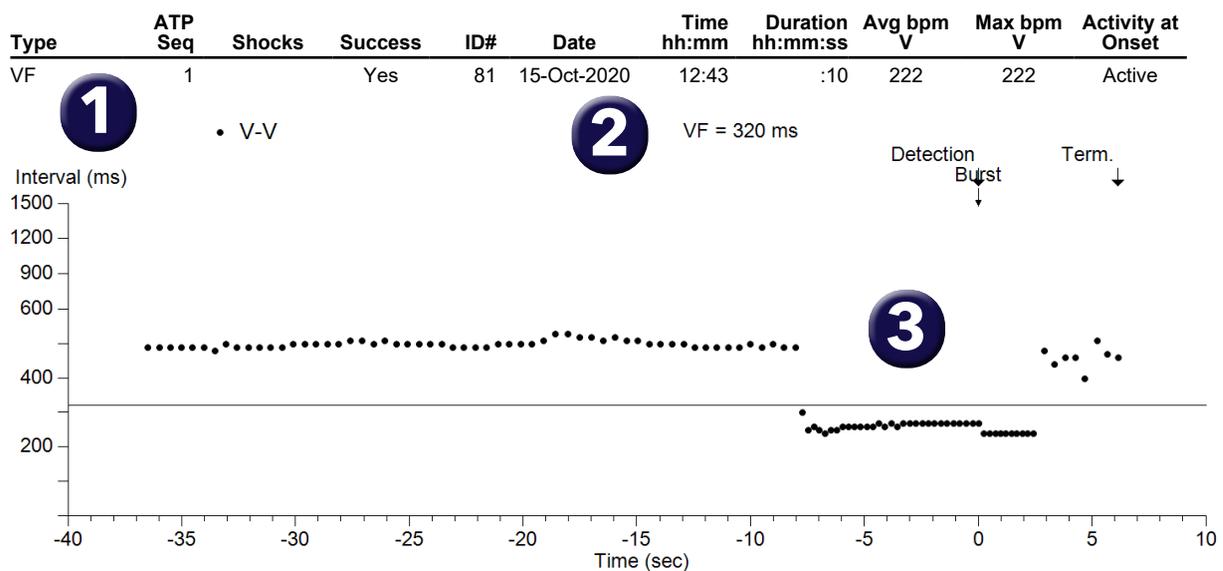
Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VF	1		Yes	81	15-Oct-2020	12:43	:10	222	222	Active

- V-V

VF = 320 ms

Detection Burst ↓   Term. ↓

Interval (ms)

1 **What was the diagnosis made by the defibrillator for this episode?**

This episode has been classified as VF by the system.

2 **How many detection zones are programmed?**

A single detection zone (VF 320 ms) has been programmed.

3 **What diagnosis does the interval plot suggest?**

The graph shows an initially stable rhythm of around 125 bpm with sudden acceleration and cycles recorded in the VF zone; a burst is delivered with a return to the initial heart rate.

EGM1: RVtip to RVring
(1 mV)

EGM2: Can to RVcoil
(2 mV)

Markers

V-V Interval (ms)

V		V		V		V		V		V		V		V		V	
S	4	S	4	S	4	S	4	S	4	S	5	S	4	S	5	S	4
	9		9		9		9		9		0		9		0		9
	0		0		0		0		0		0		0		0		0

V		F		F		F		F		F		F		F		F		F		F		F		F		F		F		F		F		F		F		F		F		F	
S	3	S	2	S	2	S	2	S	2	S	2	S	2	S	2	S	2	S	2	S	2	S	2	S	2	S	2	S	2	S	2	S	2	S	2	S	2	S	2	S	2
	0		5		6		5		4		5		5		6		6		6		6		6		7		6		7		6		7		7		7		7		7
	0		0		0		0		0		0		0		0		0		0		0		0		0		0		0		0		0		0		0		0		0

5 **6**

F		F		F		F		F																								V		V		V		V		V		V		V	
S	2	S	2	S	2	S	2	D	2	P	2	P	2	P	2	P	2	P	2	P	2	P	2	P	2	P	2	P	2	P		S	4	S	4	S	4	S	4	S	5	S	4	S
	7		7		7		7		4		4		4		4		4		4		4		4		4		4		4		8		4		6		6		0		1		7
	0		0		0		0		0		0		0		0		0		0		0		0		0		0		0		0		0		0		0		0		0		0
								VF																																		

VF Rx 1 Burst Before Charging

V	
S	
4	
6	
0	

Termination
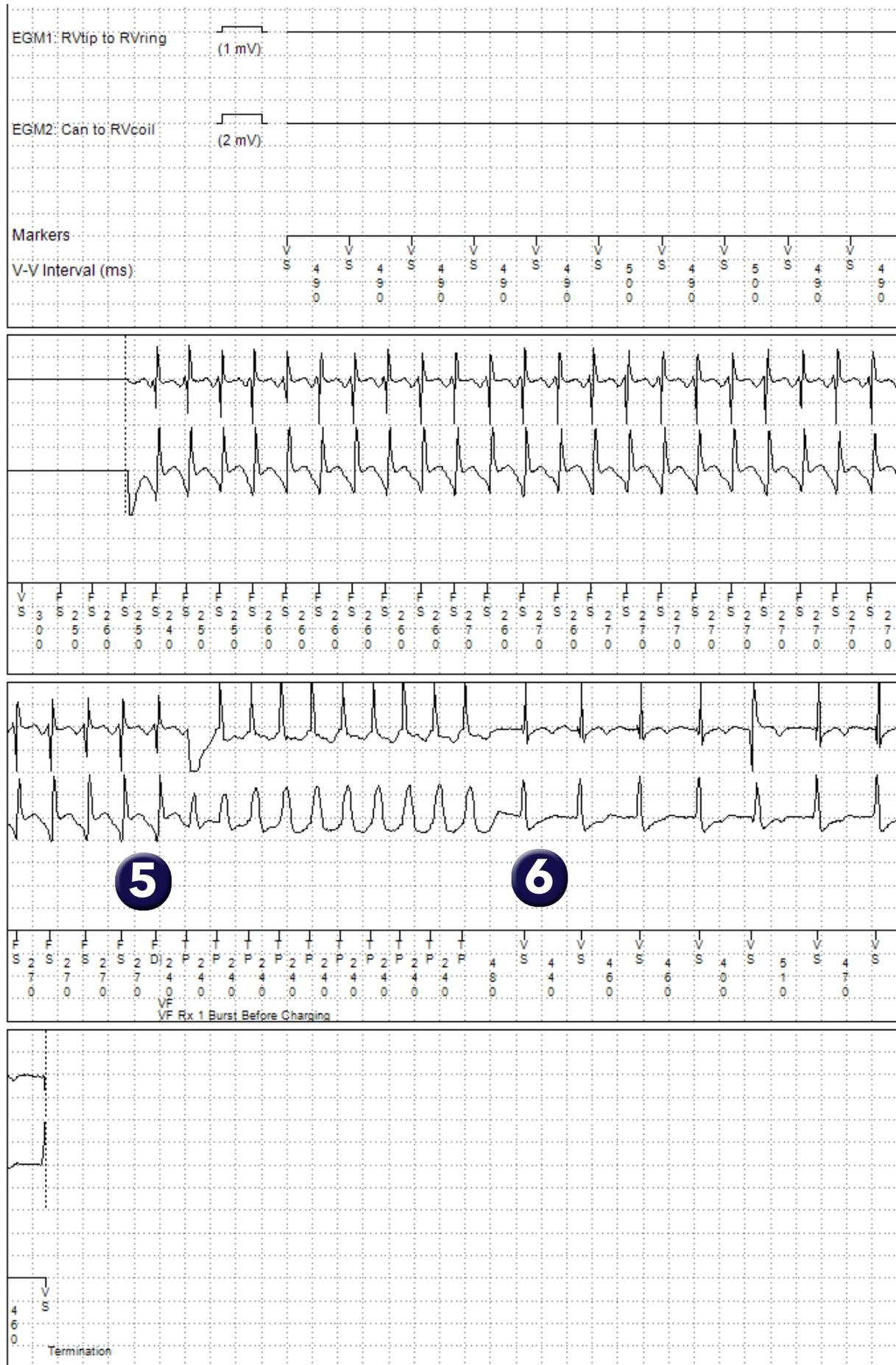
Episode Summary

Initial Type	VF (spontaneous)
Duration	10 sec
V. Max Rate	222 bpm
V. Median	222 bpm (270 ms)
Activity at onset	Active, Sensor = 94 bpm
Last Therapy	VF Rx1: Burst, Successful

Initial VT/VF Detection Withheld By

None

Therapies	Delivered	Charge	Ohms	Energy
VF Rx 1 Burst	Before Charging			
|				
Termination				

Wavelet Measurements Prior to Initial VT/VF Detection

Wavelet Result:	VT/VF	
Template Status:	OK	
-8.	No Match	34 %
-7.	No Match	52 %
-6.	No Match	34 %
-5.	No Match	43 %
-4.	No Match	49 %
-3.	No Match	40 %
-2.	No Match	46 %
-1.	No Match	40 %
0.	Detection	

7

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	320 ms (188 bpm)
FVT	Off			
VT	Off	16	12	
Monitor	Monitor	32		370 ms (162 bpm)

Wavelet

Wavelet	On, Match = 70%
Template	05-Apr-2019, Auto = On
SVT V. Limit	260 ms

Other Enhancements

Stability	Off
Onset	Off
High Rate Timeout	
VF Zone Only	Off
TWave	On
RV Lead Noise	On+Timeout
Timeout	2 min

4

Polarity   **RV**

Pace Polarity	Bipolar
Sense Polarity	Bipolar

EGM	Source	Range	Sensitivity	
EGM1	RVtip to RVring	+/- 8 mV	RV	0.3 mV
EGM2 (Wavelet)	Can to RVcoil	+/- 12 mV		

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VF	1		Yes	81	15-Oct-2020	12:43	:10	222	222	Active

No Match 34 %   No Match 52 %   No Match 34 %   No Match 43 %

6mV | 20ms

—— QRS

········ Template

No Match 49 %   No Match 40 %   No Match 46 %   No Match 40 %

7

4 How many discrimination parameters are programmed?

Wavelet is the only discrimination criterion programmed (70% match); the stability and sudden onset criteria are set to 'Off''.

5 How do you analyse the EGM in tachycardia?

This is a regular, monomorphic tachycardia with a wide QRS (shock channel) that has a different morphology to the QRS complexes recorded in the absence of tachycardia.

6 What therapy is delivered?

The VF counter is completed after 30 cycles classified as FS; a burst before charging is delivered; this helps to terminate tachycardia.

7 What do you think of the Wavelet results?

The Wavelet appearance of the analysed complexes is clearly different from the reference complex, with similarity percentages ranging from 34% to 52%; the 8 complexes were therefore considered to be different, leading to a diagnosis of ventricular arrhythmia.

Key messages

- In this example, the single-chamber defibrillator is programmed according to the latest HRS/EHRA/APHRS/LAHRS recommendations of 2019 for a primary prevention indication: programming of a single VF zone at a rate of 188 bpm, VF counter programmed to 30/40 for initial detection, programming of a monitor zone, Wavelet only discrimination programmed for cycle lengths up to 260 ms, programming of the T wave oversensing and RV lead noise algorithms.

- These international recommendations include 2 important messages in terms of single-chamber discrimination: 1) it is recommended that discrimination should be based solely on the Wavelet; therefore the criteria of sudden onset and stability should be programmed 'Off' in the first instance; in fact, when all 3 parameters are programmed 'On', all 3 must be fulfilled for the arrhythmia to be diagnosed and treated (sudden onset, stable rhythm, different morphology QRS to the reference); simultaneous programming of these 3 parameters may therefore reduce the sensitivity of the device; when Wavelet is functioning correctly in a given patient, discrimination based solely on this parameter enables virtually all tachycardias to be discriminated effectively (with the exception of SVT with aberrant conduction); 2) Wavelet must be programmed to function up to high heart rates, with a SVT V. Limit of 230 beats/minute, to reduce the risk of inappropriate therapies occurring for episodes of rapid AF (class I indication).

5 single-chamber defibrillator and SVT V. Limit

Patient

Male implanted with a primary prevention single-chamber defibrillator (Visia AF XT VR) for ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
VF	0	35J	Yes	10	19-Jun-2020	01:56	:15	429	---	Rest
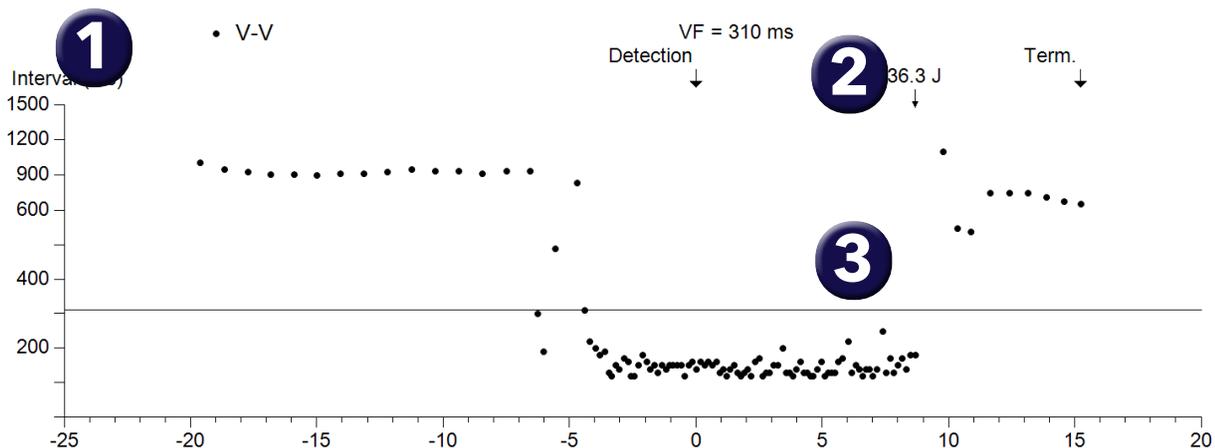
1 What was the diagnosis made by the defibrillator for this episode?

This episode has been classified as VF by the system.

2 How many detection zones are programmed?

A single zone (VF 310 ms) has been programmed.

3 What diagnosis does the interval plot suggest?

The graph shows an initially stable rhythm of around 60 bpm with sudden acceleration and very rapid cycles recorded in the VF zone; a maximum output shock is delivered with a return to the initial heart rate.
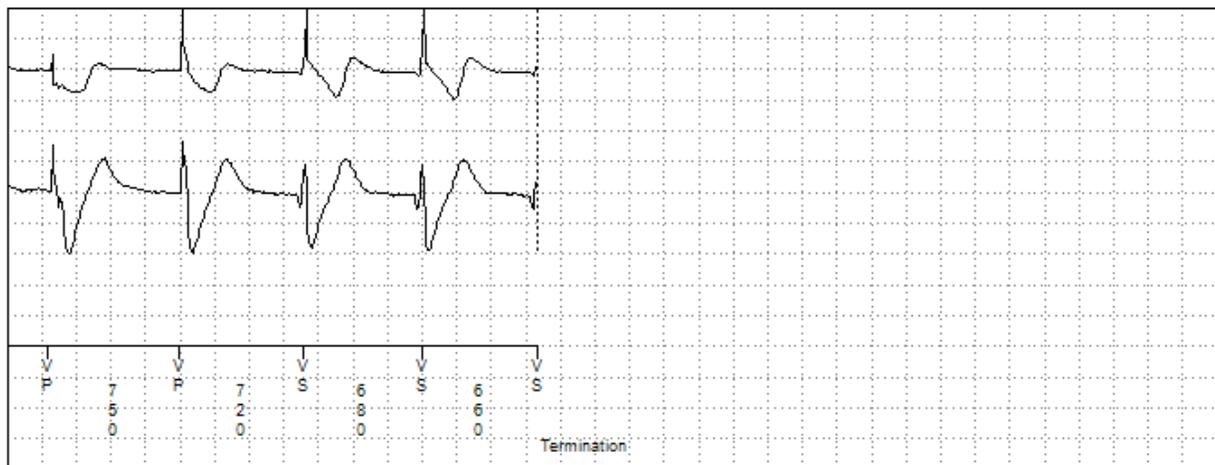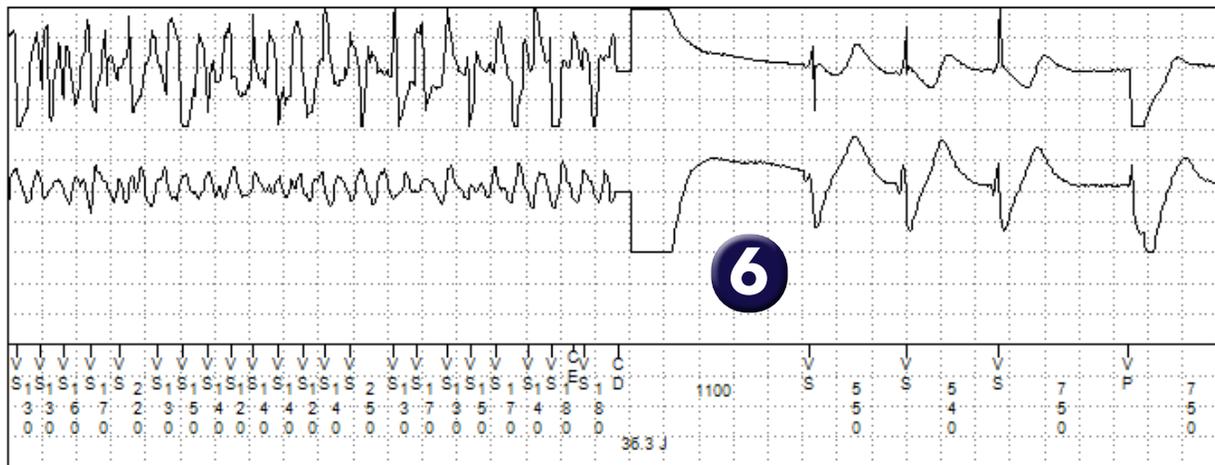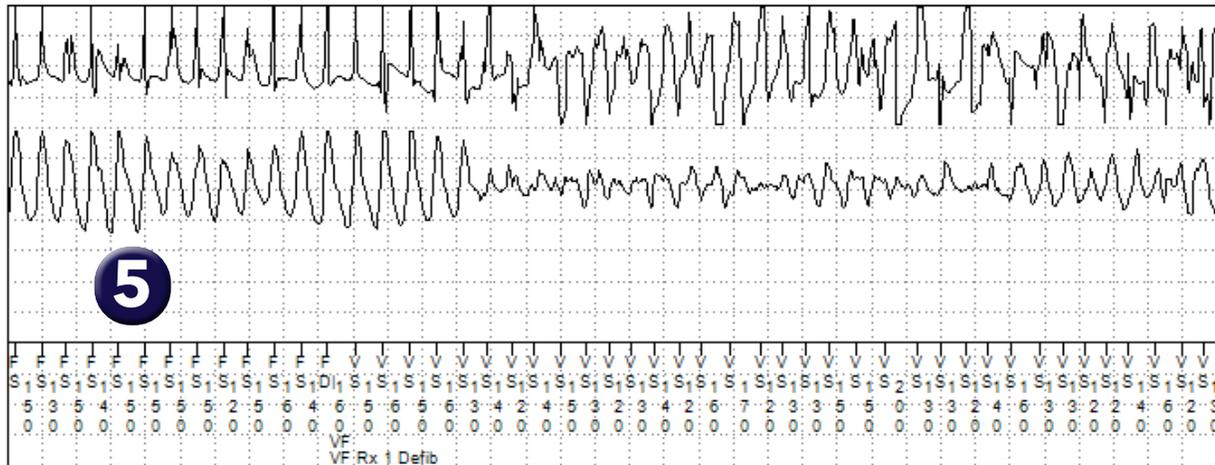
Episode Summary

Initial Type	VF (spontaneous)
Duration	15 sec
V. Max Rate	---
V. Median	400 bpm (150 ms)
Activity at onset	Rest, Sensor = 40 bpm
Last Therapy	VF Rx1: Defib, Successful

Initial VT/VF Detection Withheld By

None

Therapies	Delivered	Charge	Ohms	Energy
VF Rx 1 Defib	36.3 J	8.40 sec	73 ohms	0.0 - 35 J
|				
Termination				

Wavelet Measurements Prior to Initial VT/VF Detection

Wavelet Result:	Wavelet not applied; interval too fast or too slow		
Template Status:	OK		

-8.	No Match	---	Interval too fast
-7.	No Match	---	Interval too fast
-6.	No Match	---	Interval too fast
-5.	No Match	---	Interval too fast
-4.	No Match	---	Interval too fast
-3.	No Match	---	Interval too fast
-2.	No Match	---	Interval too fast
-1.	No Match	---	Interval too fast
0.	Detection		

(7)

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	310 ms (194 bpm)
FVT	Off			
VT	Off	16	12	
Monitor	Monitor	32		360 ms (167 bpm)

Wavelet

Wavelet	On, Match = 70%
Template	06-Jan-2020, Auto = On
SVT V. Limit	260 ms

Other Enhancements

Stability	Off
Onset	Off
High Rate Timeout	
VF Zone Only	Off
TWave	On
RV Lead Noise	On

(4)

(4) How many discrimination parameters are programmed?

Wavelet is the only discrimination criterion programmed (70% similarity); the stability and sudden onset criteria are programmed 'Off'.

5 How do you analyse the EGM in tachycardia?

This is clearly ventricular fibrillation (very rapid, irregular and polymorphic tachycardia).

6 What therapy is delivered?

The VF counter is completed after 30 cycles classified as FS; a shock is delivered after the capacitors are charged; this terminates the tachycardia.

7 What do you think of the Wavelet results?

Wavelet was not used because the 8 intervals analysed were too fast.

Key messages

- The SVT V. Limit parameter is specific to Medtronic™ devices; in fact, the SVT V. Limit is the maximum heart rate up to which discrimination based on Wavelet applies and is independent of the programmed detection zones; it can therefore be applied in the FVT or VF zone; on the other hand, the sudden onset and stability criteria are limited to the VT or FVT via VT zone; in devices from other manufacturers, no discrimination is possible in the VF zone; in this example, the VF zone starts at intervals of 310 ms and the SVT V. Limit is programmed at 260 ms; discrimination therefore applies in the VF zone for intervals between 310 and 260 ms.

- When the median cycle length of the 12 most recently detected consecutive intervals is less than this programmed limit, discrimination no longer applies; it is preferable not to program a discrimination limit that is too fast (> 230 bpm) in the majority of patients; in fact, when the heart rate exceeds this limit, the probability that the arrhythmia is supraventricular is low; moreover, incorrectly inhibiting therapies on a potentially lethal ventricular arrhythmia could prove catastrophic.

6 limitations of discrimination based on Wavelet

Patient

Male implanted with a single-chamber defibrillator (Evera XT VR) for ischaemic cardiomyopathy, hospitalised for syncope with a shock from his device.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm V	Max bpm V	Activity at Onset
FVT	4	35J	Yes	7	19-Dec-2020	01:31	:34	214	286	Rest
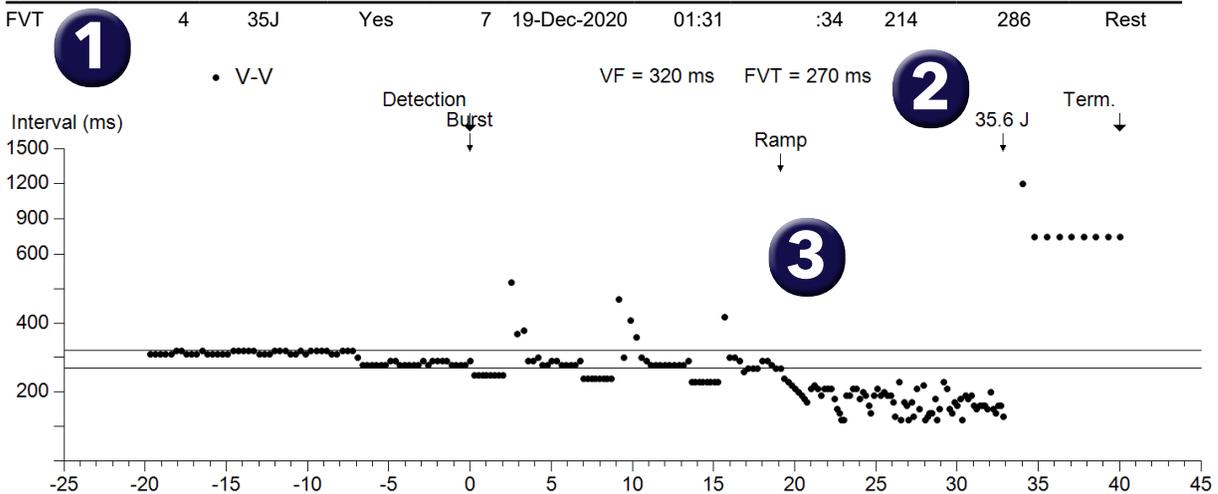
1 What is the diagnosis made by the defibrillator for this episode?

This episode has been classified FVT by the device.

2 How many detection zones are programmed?

Two detection zones have been programmed.

3 What diagnosis does the interval plot suggest?

The graph shows a rhythm initially detected in the FVT zone with 3 bursts, then a ramp which appears to accelerate the tachycardia into the VF zone; a shock re-establishes a viable rhythm.

4 How many discriminators are programmed?

Wavelet and Stability are programmed.

5   What does the WV marker mean?

Initially, the patient presented with a regular, monomorphic tachycardia; the device diagnosed SVT based on Wavelet (WV); no therapy was delivered.

6 How do you explain that a burst was delivered?

The VF counter was completed again after 30 cycles classified as FS; the appearance of the ventriculograms appeared more or less identical to that observed at the start of the trace, but Wavelet concluded VT and therefore did not withhold therapies.

7 What do you think of the Wavelet results?

The similarity percentages ranged from 52% to 61% for the 8 complexes analysed and were therefore below the programmed similarity threshold (70%), which explains the diagnosis of VT/VF.

Therapies	Delivered	Charge	Ohms	Energy
FVT Rx 1 Burst	Seq 1 to Seq 3			
|				
FVT Rx 2 Ramp	Seq 1			
|				
VF Rx 1 Defib	35.6 J	9.57 sec	68 ohms	0.0 - 35 J
|				
Termination				

Wavelet Measurements Prior to Initial VT/VF Detection

Wavelet Result:	VT/VF
Template Status:	OK

-8.	No Match	55 %
-7.	No Match	61 %
-6.	No Match	61 %
-5.	No Match	58 %
-4.	No Match	52 %
-3.	No Match	55 %
-2.	No Match	61 %
-1.	No Match	58 %
0.	Detection	

(7)

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	320 ms (188 bpm)
FVT	via VF			270 ms (222 bpm)
VT	Off	24	12	
Monitor	Monitor	32		400 ms (150 bpm)

Wavelet		**Other Enhancements**	
Wavelet	On, Match = 70%	Stability	40 ms
Template	20-Feb-2015, Auto = On	Onset	Off
SVT V. Limit	260 ms	High Rate Timeout	
		VF Zone Only	Off
		TWave	On
		RV Lead Noise	On+Timeout

(4)

No Match 55 %   No Match 61 %   No Match 61 %   No Match 58 %

6mV

20ms

—— QRS

······ Template

No Match 52 %   No Match 55 %   No Match 61 %   No Match 58 %

200
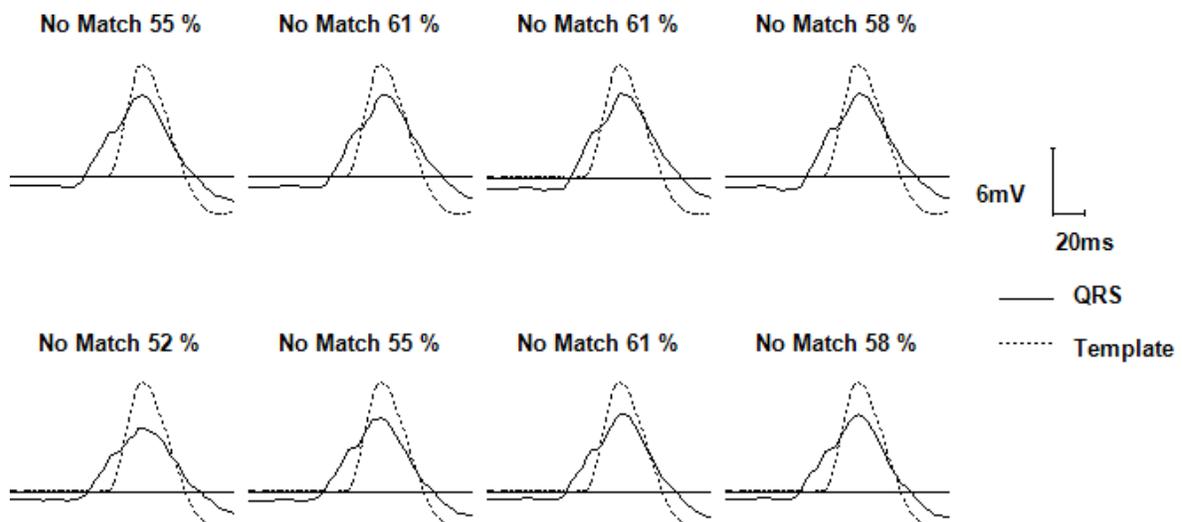
8 What effect does the ramp have?

The ramp accelerates the tachycardia into a very rapid VF.

9 What is the effect of the shock?

The shock terminates the arrhythmia.

Key messages

1. This patient had multiple episodes of atrial tachycardia which were well discriminated on the basis of morphology; he also had a few episodes which were poorly discriminated with inappropriate therapies; in this example, the discrimination error resulted in the occurrence of a ramp which induced a potentially lethal VF; a shock re-established a viable rhythm.

2. The specificity of discrimination based exclusively on Wavelet is imperfect in certain patients; discrimination only applies to initial detection and an error may lead to multiple inappropriate therapies (no discrimination if tachycardia continues after the first therapy delivered).

Certain factors may explain the imperfect specificity in certain patients:

1. Wavelet performance depends directly on the quality of the discrimination signal (EGM2), which is usually the Can-RVCoil channel. The richer the signal, the greater its amplitude. During implantation, therefore, care must be taken to ensure that the Can-RVCoil signal amplitude is >3mV. This amplitude can be measured using the Medtronic analyzer, by collecting the unipolar signal from the RV coil and measuring the peak-to-peak amplitude (to do this, print out the signal).

2. Outside the implantation procedure, you can measure the amplitude of the Can-RVCoil signal by selecting this channel on the programmer and making a printout. If the amplitude is too low, a different analysis vector can be selected (source EGM2: Can-RingRV; TipRV-CoilRV; TipRV-RingRV; Can-SCV; Can -RV-

SCV). Note that changing the EGM2 vector deactivates the noise algorithm (which only works with the Can-CoilRV vector). It should also be borne in mind that near-field signals (TipRV-CoilRV; TipRV-RingRV) are generally less rich and therefore less effective for morphology analysis.

3. On the other hand, the signal amplitude may be too large for the EGM2's sampling range (nominal +/-12mV), which may result in signal amputation. In this case, you may need to select a larger scale (Parameters->Data collection configuration->EGM2 range).

4. Automatic reference collection does not include frequency or AV delay hysteresis, so it cannot operate on a CRT-D. On a CRT-D, we recommend acquiring a Wavelet reference manually at each consultation.
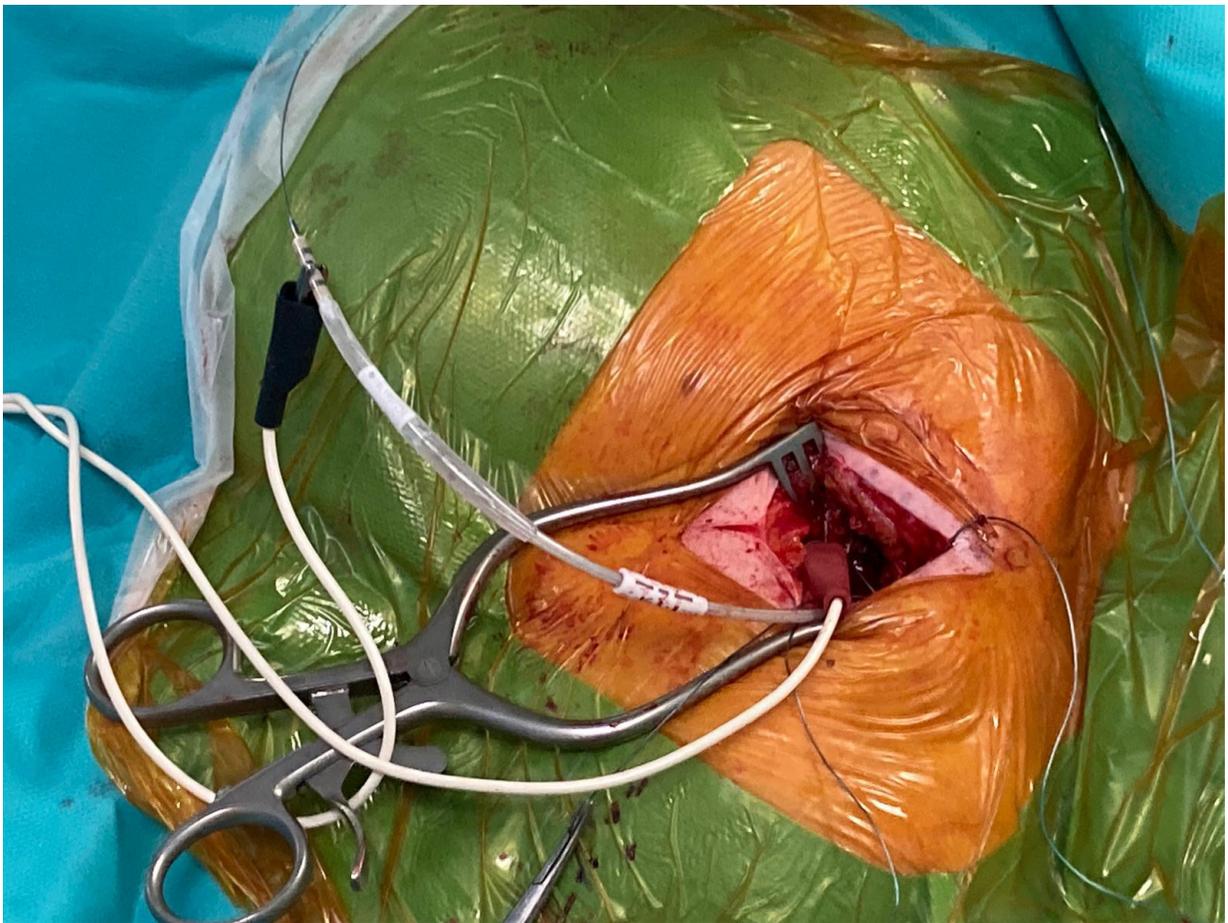
The Can - RV Coil signal can be acquired using the analyzer by connecting the unipolar signal on the RV Coil electrode and by measuring the peak-to-peak amplitude.

<table>
<tr><td>7</td><td>discrimination and atrioventricular conduction disorders</td></tr>
</table>

Patient

Male implanted with a triple-chamber defibrillator (Amplia Quad CRTD) for ischaemic cardiomyopathy with complete atrioventricular block.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
FVT	1		Yes	1067	07-Feb-2019	20:24	:15	102/176	- - -/---	Active
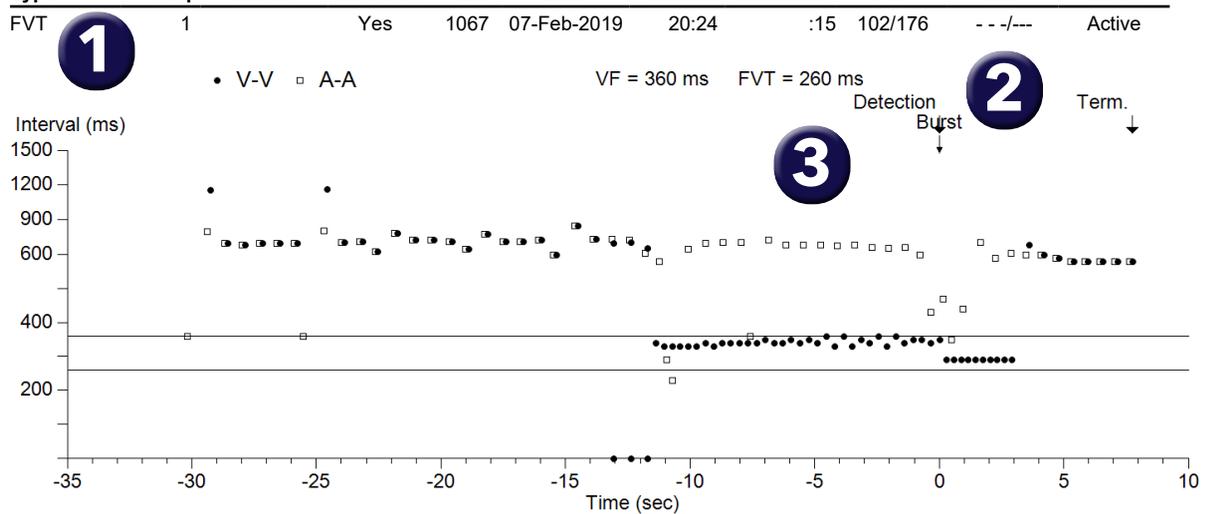
What is the diagnosis made by the defibrillator for this episode?

This episode has been classified as FVT by the device.

How many detection zones are programmed?

Two detection zones have been programmed.

What diagnosis does the interval plot suggest?

The graph initially shows a synchronised atrioventricular rhythm, then acceleration of the ventricular rhythm into the FVT zone with atrioventricular dissociation; a burst interrupts the tachycardia.
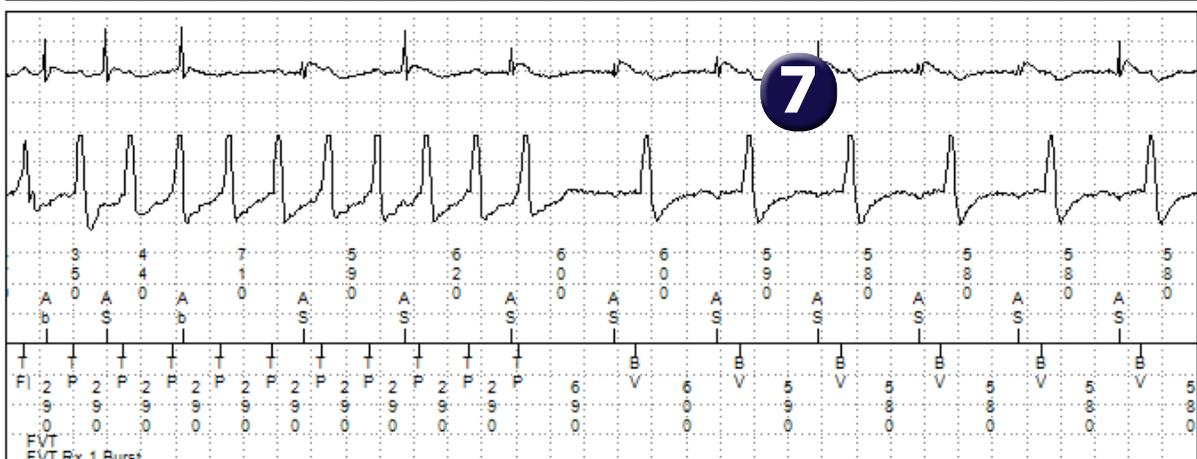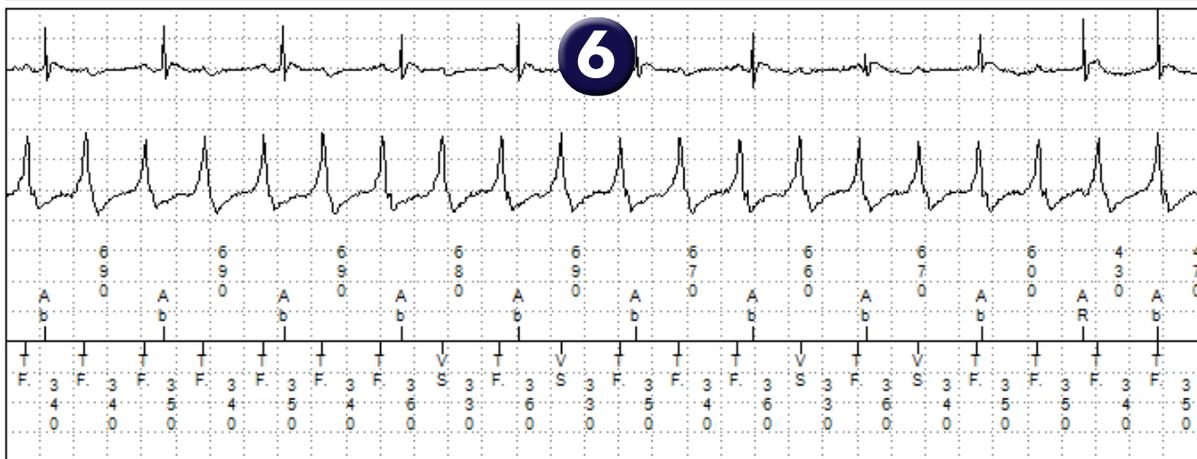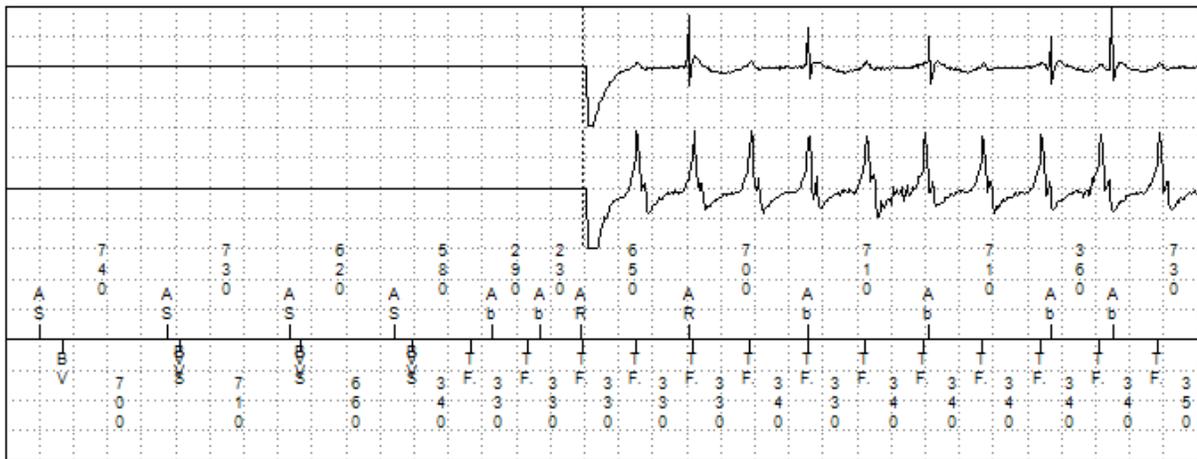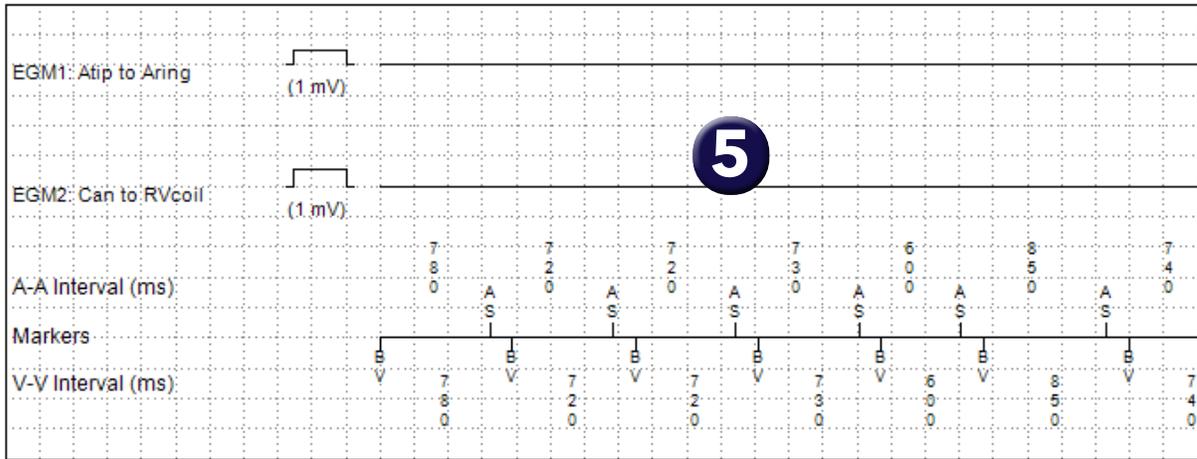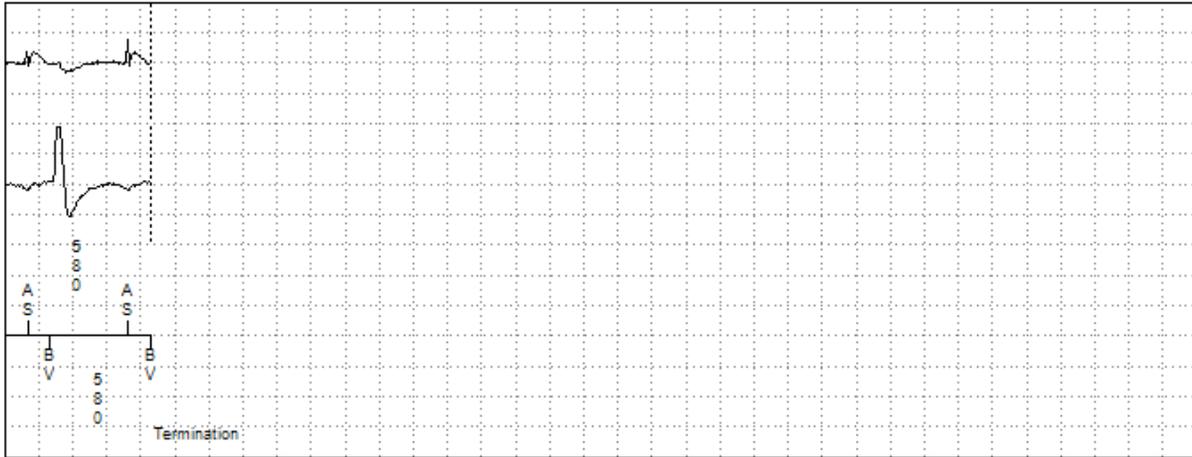
Episode Summary

Initial Type	FVT (spontaneous)
Duration	15 sec
A/V Max Rate	Unknown/---
V. Median	171 bpm (350 ms)
Activity at onset	Active, Sensor = 81 bpm
Last Therapy	FVT Rx1: Burst, Successful

Withheld By

None

Therapies	Delivered	Charge	Ohms	Energy
FVT Rx 1 Burst	Seq 1			
|				
Termination				

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	360 ms (167 bpm)
FVT	via VF			260 ms (231 bpm)
VT	Off	16	12	
Monitor	Off	32		

PR Logic/Wavelet			**Other Enhancements**	
AF/Afl	Off		Stability	Off
Sinus Tach	Off		Onset	Off
Other 1:1 SVTs	Off		High Rate Timeout	
Wavelet	Off		VF Zone Only	Off
Template			TWave	On
SVT V. Limit			RV Lead Noise	On

④

Polarity	**RV**
Pace Polarity	Bipolar
Sense Polarity	Bipolar

EGM	Source	Range	Sensitivity	
EGM1	Atip to Aring	+/- 8 mV	Atrial	0.3 mV
EGM2	Can to RVcoil	+/- 12 mV	RV	0.3 mV

4 How many discrimination parameters are programmed?

All discrimination parameters (stability, sudden onset, PR Logic, Wavelet) are set to Off.

5 What is the initial rhythm?

As expected in a resynchronised patient, the patient is initially sensed in the atrium and paced biventricularly.

6 What is your diagnosis?

It is a VT with atrioventricular dissociation

7 What is the effect of the burst?

The burst terminates the arrhythmia.

Key messages

- This patient had been implanted for primary prevention of ischaemic cardiomyopathy; he also had complete atrioventricular block justifying permanent ventricular pacing and the implantation of a triple-chamber defibrillator.

- There are now international recommendations for defibrillator programming, but these need to be tailored to the specific needs of each patient.

- In this patient, the discrimination had been programmed 'Off'; in fact, the discrimination algorithms should only be programmed in patients likely to present with conducted supraventricular tachycardia and should therefore be deactivated in patients with complete and permanent atrioventricular block; in this case, any rapid spontaneous rhythm can only be of ventricular origin.

8 discrimination and conduction disorders

Patient

Male implanted with a triple-chamber defibrillator (Amplia Quad CRTD) for ischaemic cardiomyopathy with complete atrioventricular block. (Same patient as above).

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
FVT	1		Yes	1087	11-Feb-2019	18:37	:13	171/171	- - -/171	Active
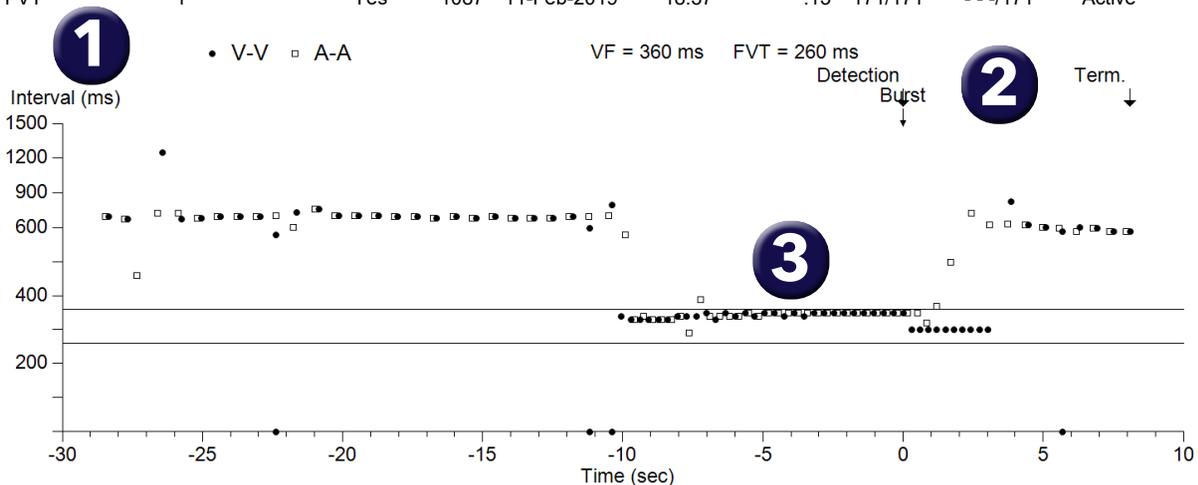
1 What was the diagnosis made by the defibrillator for this episode?

This episode has been classified FVT by the device.

2 How many detection zones are programmed?

Two detection zones have been programmed.

3 What diagnosis does the interval plot suggest?

The graph initially shows a synchronised atrioventricular rhythm, then an acceleration of the ventricular rhythm in the FVT zone with a 1/1 atrioventricular association; a burst interrupts the tachycardia
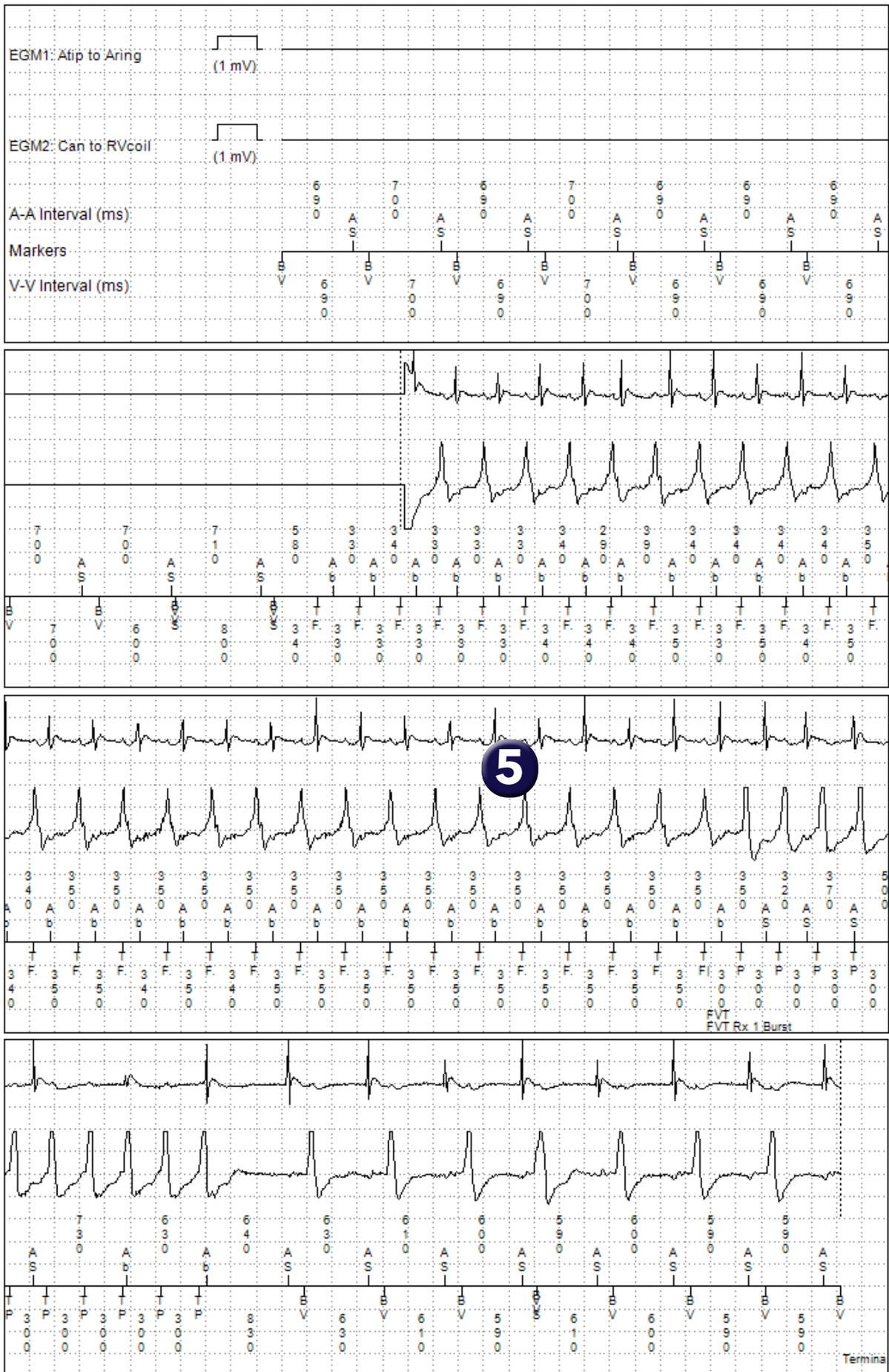
Episode Summary

		Initial VT/VF Detection
Initial Type	FVT (spontaneous)	**Withheld By**
Duration	15 sec	None
A/V Max Rate	Unknown/---	
V. Median	171 bpm (350 ms)	
Activity at onset	Active, Sensor = 81 bpm	
Last Therapy	FVT Rx1: Burst, Successful	

Therapies	Delivered	Charge	Ohms	Energy
FVT Rx 1 Burst	Seq 1			
|				
Termination				

Parameter Settings	Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	360 ms (167 bpm)
FVT	via VF			260 ms (231 bpm)
VT	Off	16	12	
Monitor	Off	32		

PR Logic/Wavelet

AF/Afl	Off
Sinus Tach	Off
Other 1:1 SVTs	Off
Wavelet	Off
Template	
SVT V. Limit	

Other Enhancements

Stability	Off
Onset	Off
High Rate Timeout	
VF Zone Only	Off
TWave	On
RV Lead Noise	On

④

Polarity   **RV**

Pace Polarity	Bipolar
Sense Polarity	Bipolar

EGM	Source	Range	Sensitivity	
EGM1	Atip to Aring	+/- 8 mV	Atrial	0.3 mV
EGM2	Can to RVcoil	+/- 12 mV	RV	0.3 mV

④ ## How many discrimination parameters are programmed?

All discrimination parameters (stability, onset, PR Logic, Wavelet) are set to Off.

⑤ ## What is your diagnosis?

This is probable VT with 1/1 atrioventricular association (start on ventricular activity, 1/1 retrograde conduction).

Key messages

- This is the same patient as the one in the previous tracing after recording a new episode of VT; however, the tracing is different with atrioventricular dissociation in the first episode and 1/1 retrograde atrial conduction in this second episode; this patient therefore has an anterograde conduction disorder (complete atrioventricular block) with preserved retrograde conduction.

- 1/1 tachycardias are probably the most difficult to discriminate for a double or triple chamber defibrillator; therefore this tracing clearly illustrates the need to turn off the different discriminators in patients with complete atrioventricular block to avoid errors if retrograde conduction is preserved or in the presence of a bi-tachycardia (VT + AF), another situation where discrimination is difficult.

9 using single-chamber discriminators in a dual-chamber defibrillator

Patient

Male implanted with a dual-chamber defibrillator (EnTrust) for ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
SVT-Onset				24	25-Nov-2007	07:52	:09:45	82/143	97/146	Rest

● V □ A-A   VF = 320 ms   VT = 430 ms
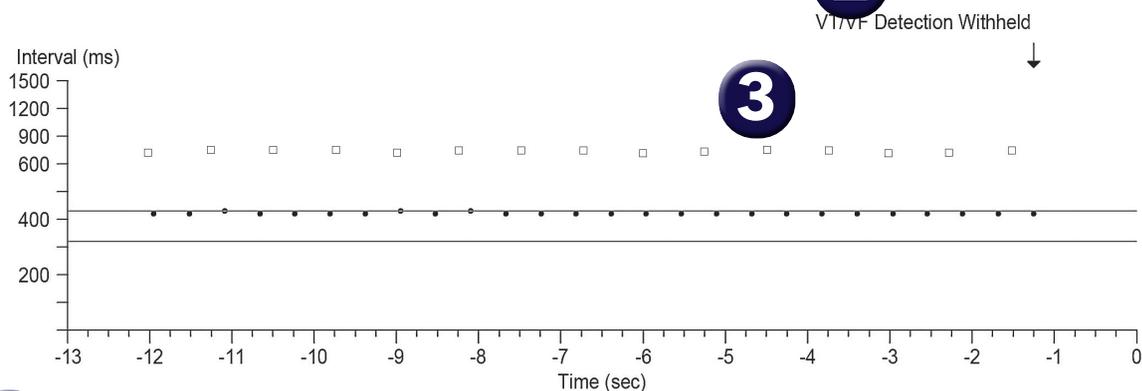
VT/VF Detection Withheld

Interval (ms) plot — Time (sec) from -13 to 0

1 What was the diagnosis made by the defibrillator for this episode?

This episode was classified as SVT-Onset by the system.

2 How many detection zones are programmed?

Two detection zones have been programmed with a VT zone of 430 to 320 ms.

3 What diagnosis does the interval plot suggest?

The graph shows atrioventricular dissociation (ventricular rhythm faster than atrial rhythm); the ventricular rhythm oscillates around the lower limit of the VT zone.

4 How many discrimination parameters are programmed?

All the discrimination parameters (stability, hard start, PR Logic) available on this legacy platform are set to 'On'.

5 What is your diagnosis?

The diagnosis of VT is obvious, as the ventricular rhythm is faster than the atrial rhythm; the Reset. Onset marker reflects the fact that the sudden onset criterion has not been fulfilled; the cycles are therefore classified as VS even when they correspond to the VT zone.

Episode Summary

Initial Type	SVT - Onset (spontaneous)
Duration	9.8 min
A/V Max Rate	97 bpm/146 bpm
V. Median	143 bpm (420 ms)
Activity at onset	Rest, Sensor = 79 bpm

Episode transitioned to a VT/VF episode.

SVT Criteria Triggered

Onset

5

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	12/16	9/12	320 ms (188 bpm)
FVT	Off			
VT	On	16	12	430 ms (140 bpm)
Monitor	Off	20		

PR Logic

AF/Afl	On
Sinus Tach	On
Other 1:1 SVTs	Off
SVT V. Limit	320 ms

Other Enhancements

Stability	40 ms
Onset	On (81%)
High Rate Timeout	Off

4

EGM	EGM1	EGM2	Sensitivity	
Source	Atip to Aring	Vtip to Vring	Atrial	0.3 mV
Range	+/- 8 mV	+/- 8 mV	RV	0.3 mV

Key messages

- On a dual-chamber or triple-chamber defibrillator, it is possible to program the 2 single-chamber discrimination parameters (other discriminations: sudden onset and stability) separately or in association with PR Logic; these parameters take precedence over analysis by PR Logic; in other words, if sudden onset is programmed in conjunction with PR Logic, the first discrimination step consists of validating the single-chamber criterion; if, as in this example, the device does not find a sudden onset, it concludes that there is an SVT without further analysis and without consulting PR Logic.

- In this patient, the diagnosis of VT seemed obvious to the cardiologist who analysed the tracing, the atrioventricular dissociation being pathognomonic; an analysis using PR Logic would also have led to the diagnosis of VT, the ventricular rate being faster than the atrial rate.

213

- This patient presents with a tachycardia oscillating around the lower limit of the VT zone, which explains why the analysis is misleading and why the defibrillator considers that there was no sudden onset; the most likely scenario is that the ventricular rate went from a normal rate (60 beats/minute) to a rapid rate just below the VT zone at the start of the tachycardia (138 to 139 beats/minute) with a slight acceleration of the rate thereafter into the VT zone (140-141 beats/minute).

- This tachycardia therefore had a sudden onset but was not diagnosed by the device; in fact, the criterion is calculated by comparing the first intervals corresponding to the VT zone with the 4 previous cycles; the device is therefore fooled in this example (no jump in rate between the 4 cycles at 139 beats/minute and the 4 cycles at 140 beats/minute).

- The easiest solution in this patient is to turn off this discrimination criterion in favour of PR Logic.

- The third single-chamber discrimination parameter (Wavelet) can be programmed in conjunction with PR Logic; its position in the diagnostic tree differs from that of the other 2 parameters and will be described in more detail when subsequent tracings are analysed.

10 · triple-chamber defibrillator and V limit. SVT

Patient

Male implanted with a triple-chamber defibrillator (Claria Quad CRTD) for dilated cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VF	0	35J	Yes	1	27-Feb-2019	11:16	:17	90/273	- - -/---	Active
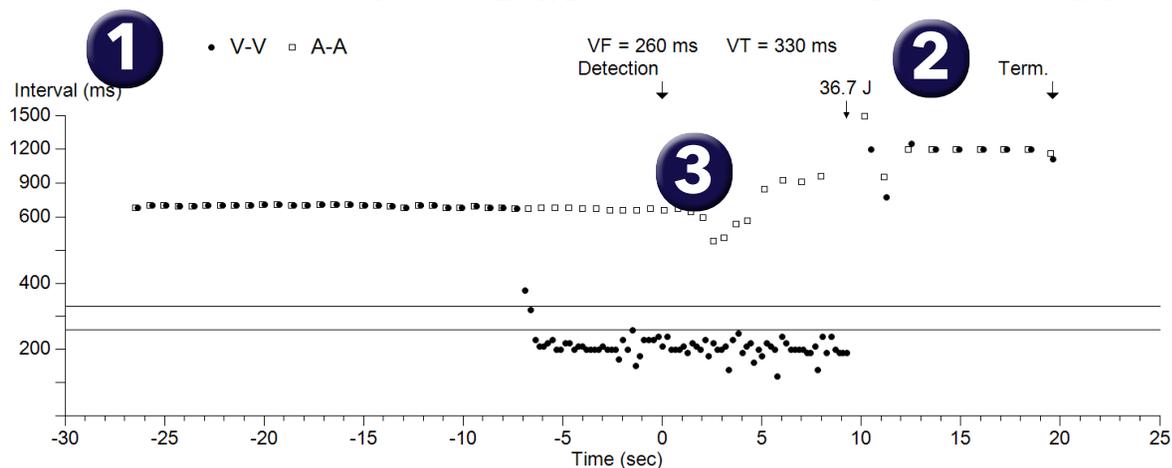
1 What is the diagnosis made by the defibrillator for this episode?

This episode has been classified as VF by the system.

2 How many detection zones are programmed?

Two detection zones have been programmed.

3 What diagnosis does the interval plot suggest?

The graph shows atrioventricular dissociation (ventricular rhythm faster than the atrial rhythm) with very rapid and irregular ventricular cycles; a maximum output shock terminates the arrhythmia.

EGM1: Atip to Aring

(1 mV)

EGM2: Can to RVcoil

(1 mV)

A-A Interval (ms)

Markers

V-V Interval (ms)

VF
VF Rx 1 Defib

>2000

36.7 J

1200

1200

1250

A/V Max Rate   Unknown/---
V. Median   261 bpm (230 ms)
Activity at onset   Active, Sensor = 83 bpm
Last Therapy   VF Rx1: Defib, Successful

Therapies	Delivered	Charge	Ohms	Energy
VF Rx 1 Defib	36.7 J	8.88 sec	64 ohms	0.0 - 35 J
|				
Termination				

Wavelet Measurements Prior to Initial VT/VF Detection

Wavelet Result: Wavelet not applied; interval too fast or too slow
Template Status: OK

-8.	No Match	---	Interval too fast
-7.	No Match	0 %	
-6.	No Match	---	Interval too fast
-5.	No Match	---	Interval too fast
-4.	No Match	---	Interval too fast
-3.	No Match	---	Interval too fast
-2.	No Match	---	Interval too fast
-1.	No Match	25 %	
0.	Detection		

6

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	260 ms (231 bpm)
FVT	Off			
VT	On	32	12	330 ms (182 bpm)
Monitor	Off	32		

PR Logic/Wavelet

AF/Afl	On
Sinus Tach	On
Other 1:1 SVTs	Off
Wavelet	On, Match = 70%
Template	20-Nov-2018, Auto = Off
SVT V. Limit	260 ms

Other Enhancements

Stability	Off
Onset	On (81%)
High Rate Timeout	
VF Zone Only	Off
All Zones	Off
TWave	On
RV Lead Noise	On

4

Polarity   RV

4 How many discrimination parameters are programmed?

The discrimination parameters (sudden onset, PR Logic, Wavelet) are programmed with a SVT V. Limit of 260 ms.

5 What is your diagnosis?

The diagnosis of VF is obvious with atrioventricular dissociation and wide, irregular, polymorphic QRS complexes.

6 Why isn't Wavelet used in this episode?

Wavelet and PR Logic were not used, as the ventricular intervals were too fast and exceeded the programmed SVT V. Limit.

Key messages

- This episode corresponds to ventricular fibrillation with intervals measured at 200 ms (300 bpm).

- For this heart rate range, it is necessary for the defibrillator to differentiate between physiological arrhythmia and oversensing of noise (lead dysfunction) or oversensing of the T wave; in fact, when oversensing occurs, the cycles detected can be very fast; this explains why the RV lead noise and T wave algorithms remain active for very high rates.

- Conversely, the probability of a supraventricular arrhythmia reaching these very high rates is very low; as with a single-chamber defibrillator, a SVT V. Limit can be programmed independently of the detection zone programming.

- The SVT V. Limit applies to both PR Logic and Wavelet.

11 ## dual-chamber defibrillator and atrioventricular dissociation

Patient

Male implanted with a dual-chamber defibrillator (Cobalt DR) for hypertrophic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
FVT	1		Yes	50	04-Oct-2022	23:59	:12	88/188	---/188	Rest

- • V-V Paced   ∘ V-V Sensed   ■ A-A Paced   □ A-A Sensed

FVT = 280 ms   VF = 310 ms   VT = 360 ms
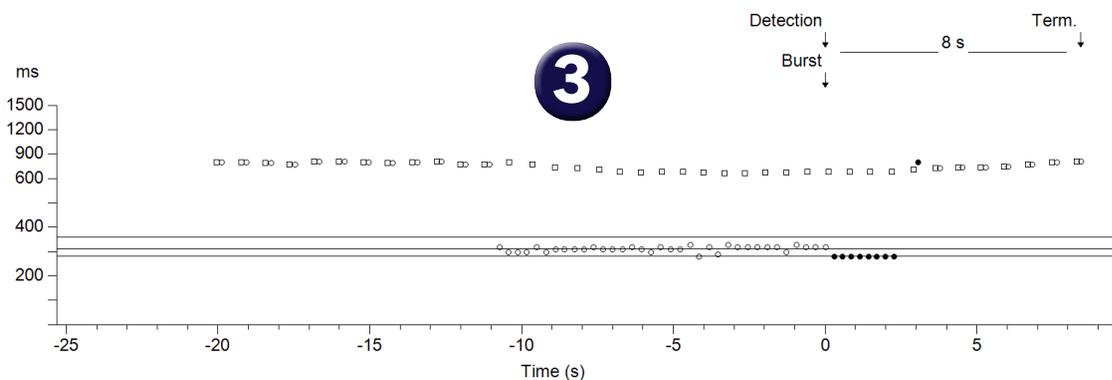
1 What was the diagnosis made by the defibrillator for this episode?

This episode has been classified FVT by the device.

2 How many detection zones are programmed?

Three detection zones have been programmed.

3 What diagnosis does the interval plot suggest?

The graph suggests a diagnosis of VT with atrioventricular dissociation (ventricular rhythm faster than the atrial rhythm); the burst allows reduction.

EGM1: Atip to Aring
(1 mV)

EGM3: RVtip to RVring
(1 mV)

A-A (ms)

Markers

V-V (ms)

Strip 1 (top panel):

A-A: 800 790 780 810 810 800

Markers: AS AS AS AS AS AS
VS VS VS VS VS VS

V-V: 800 800 790 780 810 810 800

Strip 2 (middle panel):

790 800 810 780 780 800 780 740 730

AS AS AS AS AS AS Ab AR AR

VS VS VS VS VS VS 320 300 300 300 320 310 310

790 800 810 780 780

VS S S F• S F• S F• S S F•

Strip 3 (bottom panel):

710 690 680 690 690 680 670 670 680 680

AR AR AR AR Ab AR AR AR AR Ab

310 320 310 310 310 300 320 310 300 280 290 320 320 320 320 320

S S S S S S S S F• S S F• S S S S S S F•

❺

Episode Summary

Initial Type	VF (spontaneous)
Duration	17 sec
A/V Max Rate	Unknown/---
V. Median	261 bpm (230 ms)
Activity at onset	Active, Sensor = 83 bpm
Last Therapy	VF Rx1: Defib, Successful

Initial VT/VF Detection Withheld By

None

Therapies

Therapies	Delivered	Charge	Ohms	Energy
VF Rx 1 Defib	36.7 J	8.88 sec	64 ohms	0.0 - 35 J
|				
Termination				

Wavelet Measurements Prior to Initial VT/VF Detection

Wavelet Result:	Wavelet not applied; interval too fast or too slow
Template Status:	OK

-8.	No Match	---	Interval too fast
-7.	No Match	0 %	
-6.	No Match	---	Interval too fast
-5.	No Match	---	Interval too fast
-4.	No Match	---	Interval too fast
-3.	No Match	---	Interval too fast
-2.	No Match	---	Interval too fast
-1.	No Match	25 %	
0.	Detection		

6

Parameter Settings

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	260 ms (231 bpm)
FVT	Off			
VT	On	32	12	330 ms (182 bpm)
Monitor	Off	32		

PR Logic/Wavelet

AF/Afl	On
Sinus Tach	On
Other 1:1 SVTs	Off
Wavelet	On, Match = 70%
Template	20-Nov-2018, Auto = Off
SVT V. Limit	260 ms

Other Enhancements

Stability	Off
Onset	On (81%)
High Rate Timeout	
VF Zone Only	Off
All Zones	Off
TWave	On
RV Lead Noise	On

4

Polarity	RV

No Match 40 %   No Match 40 %   No Match 46 %   No Match 40 %

20 ms

——— QRS

········· Template

No Match 40 %   No Match 40 %   No Match 46 %   No Match 43 %

4 How many discrimination parameters are pro-grammed?

The discrimination parameters (PR Logic and Wavelet) are programmed with a SVT V.limit of 260 ms.

5 What is your diagnosis?

The diagnosis of VT is obvious with atrioventricular dissociation.

6 What are the results of Wavelet?

Wavelet supports the diagnosis of VT, with none of the QRS complexes analysed judged to be similar to the reference template.

Key messages

- A double or triple-chamber defibrillator can be used to compare the atrial and ventricular rates; for both the clinician and defibrillator, the presence of a ventricular rate faster than the atrial rate confirms the ventricular origin of the tachycardia.

- In a dual or triple chamber defibrillator, the PR Logic algorithm is used to discriminate the origin of the tachycardia and differentiate between ventricular and supra-ventricular tachycardias by studying the relationship between atrial and ventricular activity and comparing the 2 respective rates.

- Discrimination by PR Logic only applies during the initial detection phase and not during the re-detection phase; PR Logic only works for heart rates below the programmed limit of supra-ventricular tachycardia and can therefore be active in the VF zone depending on programming.

- PR Logic gives its diagnosis once the initial VT or VF counter has been filled.

- PR Logic discrimination is based on the continuous and simultaneous assessment of 6 criteria, which can sometimes make it difficult to explain in detail how it works.

- In this example, the diagnosis of VT is obvious to the doctor because of atrio-ventricular dissociation, which is most frequently the case; in fact, during an episode of VT, the demonstration of a ventricular rate faster than the atrial rate is much more common than the observation of a 1/1 ratio (retrograde conduction) or a bi-tachycardia.

- Diagnosis is also straightforward with PR Logic; one of the essential steps in diagnosis using PR Logic is a comparison between ventricular and atrial rates (measurement of the median value of RR intervals and PP intervals over the last 12 cycles); when the ventricular rate is judged to be faster than the atrial rate, the device concludes that VT has occurred without further analysis.

12 PR Logic versus Wavelet

Patient

Male implanted with a dual-chamber defibrillator (Evera XT DR) for dilated cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VT	1		No	451	03-Jul-2021	10:33	:14	59/194	- - -/286	Active
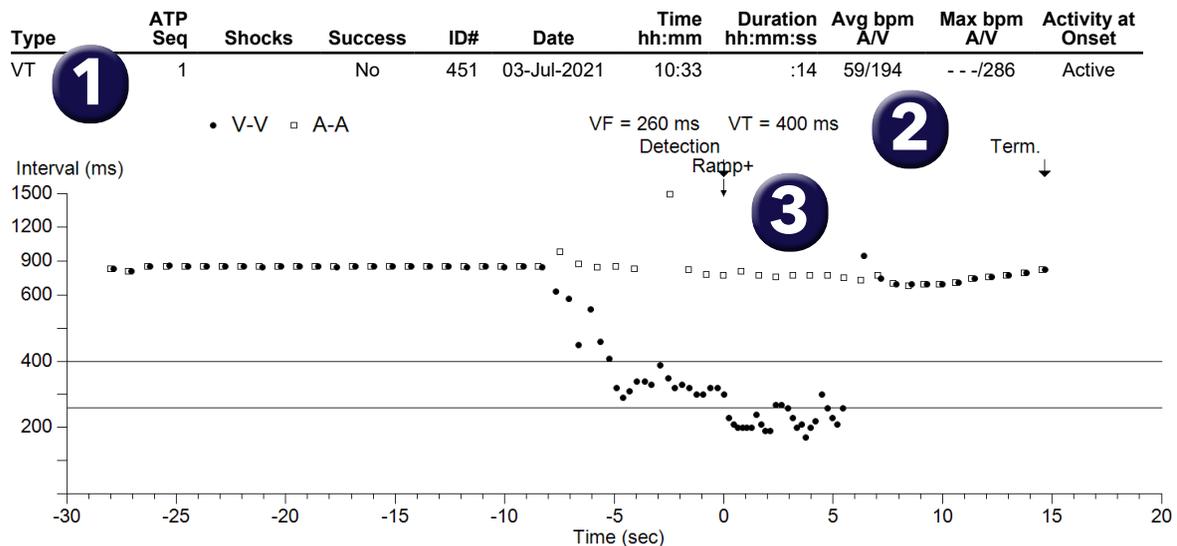
1 What is the diagnosis made by the defibrillator for this episode?

This episode was classified VT by the device.

2 How many detection zones are programmed?

Two detection zones have been programmed with a VT zone of 400 to 260 ms.

3 What diagnosis does the interval plot suggest?

The graph shows an appearance compatible with a ventricular arrhythmia (atrioventricular dissociation) accelerating after a Ramp + and terminating spontaneously.

EGM1: Atip to Aring (0.1 mV)

EGM3: RVtip to RVring (1 mV)

A-A Interval (ms)

Markers

V-V Interval (ms)

T Rx 2 Ramp+

VF Rx 1 Defib

Aborted

Therapies	Delivered	Charge	Ohms	Energy

One or more therapies aborted due to inability to confirm VT/VF or synchronize a CV therapy.

VT Rx 2 Ramp+   Seq 1
    |

VF Rx 1 Defib   Aborted   4.07 sec   35.0 J
    |

Termination

Wavelet Measurements Prior to Initial VT/VF Detection

Wavelet Result:	Wavelet not applied; V. rate greater than A. rate
Template Status:	OK

-8.	Match	73 %
-7.	No Match	67 %
-6.	No Match	67 %
-5.	Match	76 %
-4.	No Match	67 %
-3.	Match	70 %
-2.	Match	73 %
-1.	Match	70 %
0.	Detection	

6

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	260 ms (231 bpm)
FVT	Off			
VT	On	16	12	400 ms (150 bpm)
Monitor	Off	32		

PR Logic/Wavelet

AF/Afl	On
Sinus Tach	On
Other 1:1 SVTs	Off
Wavelet	On, Match = 70%
Template	03-Aug-2020, Auto = On
SVT V. Limit	260 ms

Other Enhancements

Stability	Off
Onset	Off
High Rate Timeout	
VF Zone Only	Off
All Zones	Off
TWave	On
RV Lead Noise	On+Timeout
Timeout	2 min

4

Polarity   **RV**

Pace Polarity	Bipolar
Sense Polarity	Bipolar

Match 73 %	No Match 67 %	No Match 67 %	Match 76 %

6mV

20ms

—— QRS

········ Template

No Match 67 %	Match 70 %	Match 73 %	Match 70 %
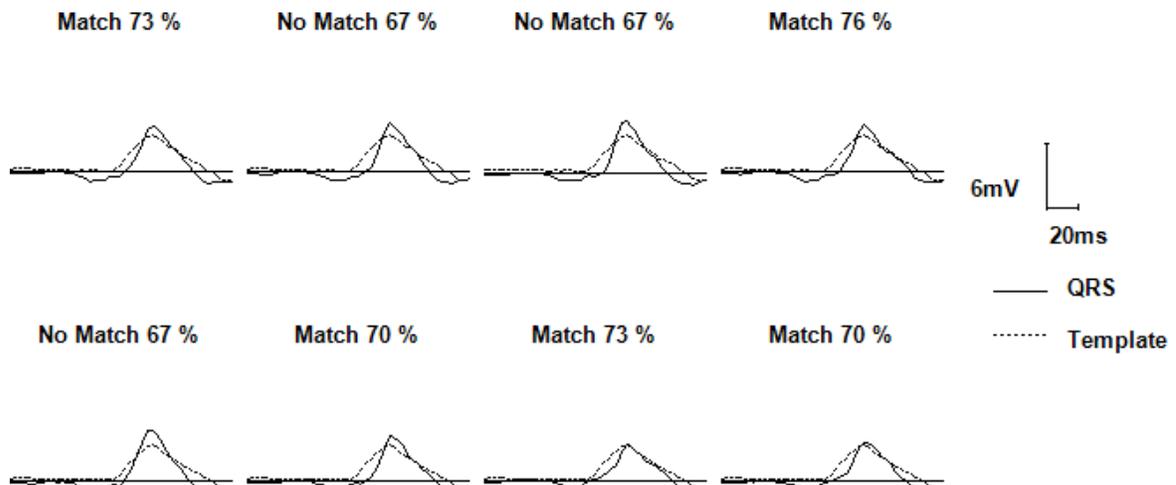
④ **How many discrimination parameters are programmed?**

PR Logic and Wavelet are programmed with a SVT V.limit of 260 ms.

⑤ **What is your diagnosis?**

This is a ventricular arrhythmia that accelerates after a Ramp+ and terminates spontaneously.

⑥ **What are the results of Wavelet?**

Wavelet favours the diagnosis of SVT, with the majority of analysed QRS complexes judged to be similar to the reference template; Wavelet is not used however, as the ventricular rate is faster than the atrial rate.

Key messages

- In a dual or triple chamber defibrillator, international recommendations advise simultaneous programming of PR Logic and Wavelet.

- It is important to understand the decision-making process when these 2 algorithms are programmed; when the ventricular rate is judged to be faster than the atrial rate, PR Logic concludes the arrhythmia is VT/VF and the device diagnoses VT without further analysis.

- In this case (V > A), the device does not consult the Wavelet analysis, and therefore cannot modify the VT diagnosis made by PR Logic.

- This example shows the advantage of prioritising PR Logic over Wavelet when the ventricular rate is faster than the atrial rate; in fact, the diagnosis is obvious with PR Logic whereas Wavelet would have concluded SVT and would have inhibited therapies.

13 · dual-chamber discrimination and atrial detection

Patient

Male implanted with a dual-chamber defibrillator (Evera XT DR) for ischaemic cardiomyopathy.

Type	SAT Séq.	Chocs	Succès	Nº ID	Date	Heure hh:mm	Durée hh:mm:ss	Min-¹ moy. A/V	Min-¹ max. A/V	Activité en Début
TV	5		Oui	42	02-Aug-2015	11:31	:01:05	188/188	286/194	Actif

①
V-V   □ A-A   FV = 270 ms   TV = 350 ms   **②**
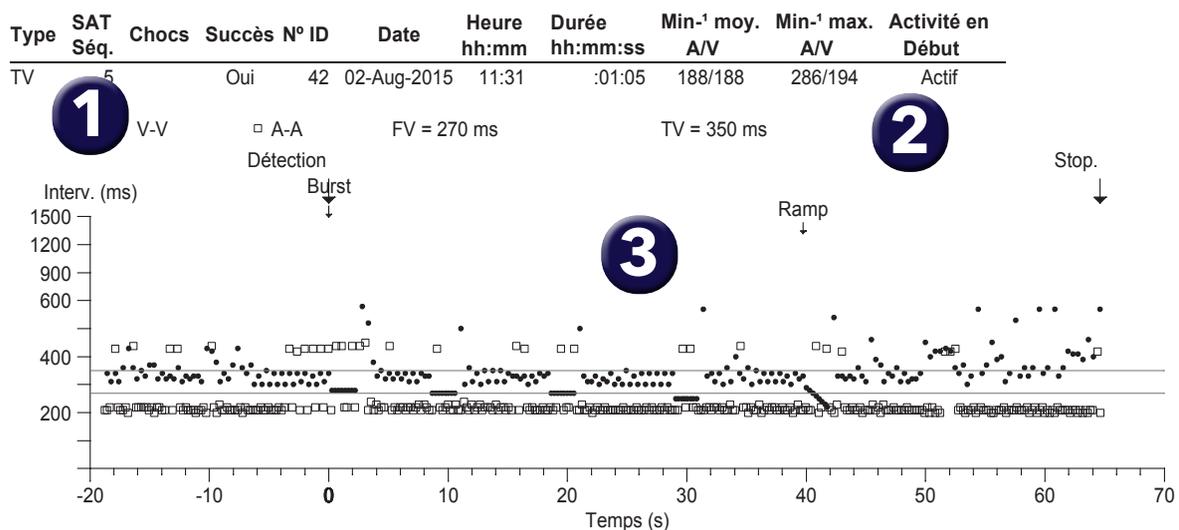
Détection

① What was the diagnosis made by the defibrillator for this episode?

This episode was classified as VT by the device.

② How many detection zones are programmed?

Two detection zones have been programmed with a VT zone of 350 to 270 ms.

③ What diagnosis does the interval plot suggest?

The graph shows a rapid atrial rhythm with occasional slowing; the ventricular response is relatively irregular; 4 bursts and a ramp are delivered.

EGM1: DistaleA./AnodeA.
(1 mV)

EGM3: DistaleVD/AnodeVD.
(1 mV)

A-A (ms):

Marqueurs

V-V (ms):

4

5

TV:
TV Tt 1 Burs
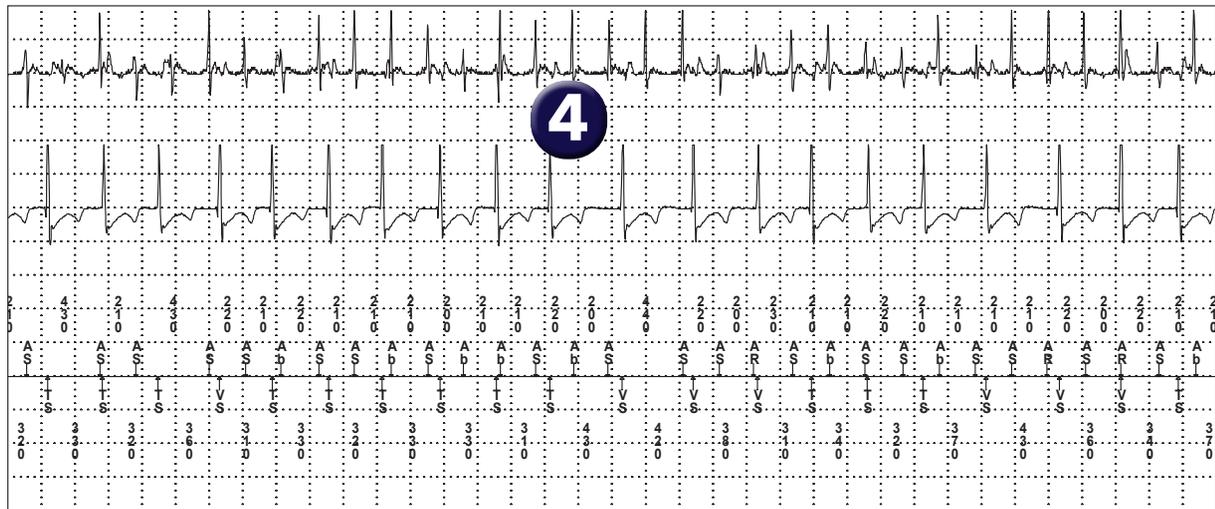
4 What is your diagnosis?

The tracing showed atrial fibrillation with irregular atrioventricular conduction, supporting the diagnosis of conducted AF.

5 How do you rate the quality of atrial sensing?

The tracing shows intermittent atrial undersensing; over these few seconds, the ventricular rate appears faster than the atrial rate to the device; when the VT counter is full, the defibrillator concludes that the diagnosis is VT (V>A).

Key messages

- This episode demonstrates one of the limitations of prioritising PR Logic over Wavelet.

- In this patient, we found multiple episodes of conducted AF that were well discriminated by PR Logic or Wavelet, but in this episode inappropriate therapies were delivered.

- PR Logic is based on differential analysis between atrial and ventricular rates; one of the basic rules of operation of this algorithm is that if the ventricular rate is judged to be faster than the atrial rate, the device concludes VT without further analysis (no analysis of Wavelet, which would have enabled the diagnosis to be corrected); this therefore exposes the patient to the risk of inappropriate therapies in the presence of atrial undersensing, as in this example (ventricular rate incorrectly classified as higher than the atrial rate).

- If these episodes recur and there is no programming margin to optimise the quality of atrial sensing, it may be advisable to turn off PR Logic and base discrimination solely on Wavelet analysis.

14 double-chamber discrimination and exertion in a young patient

Patient

31-year-old male implanted with a triple-chamber defibrillator (Amplia Quad CRTD) for dilated cardiomyopathy.
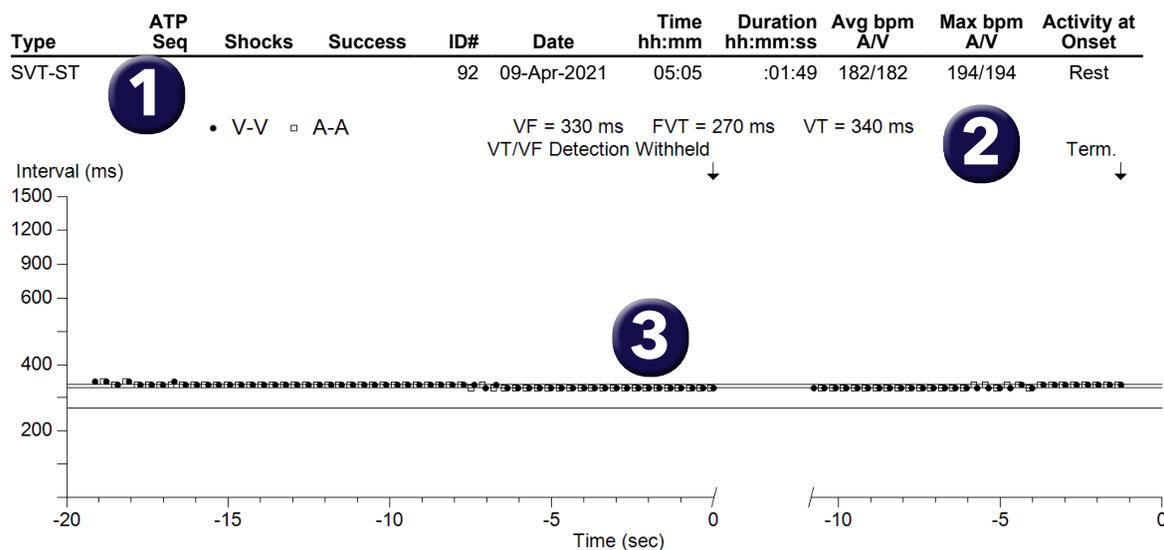
Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
SVT-ST	**1**			92	09-Apr-2021	05:05	:01:49	182/182	194/194	Rest

• V-V   □ A-A

VF = 330 ms   FVT = 270 ms   VT = 340 ms   **2**   Term.

VT/VF Detection Withheld ↓   ↓

1 What was the diagnosis made by the defibrillator for this episode?

This episode has been classified SVT- Sinus Tach by the device.

2 How many detection zones are programmed?

Three detection zones have been programmed with a VT zone of 340 to 330 ms.

3 What diagnosis does the interval plot suggest?

The graph shows a 1/1 tachycardia with progressive acceleration then deceleration suggestive of sinus tachycardia.

EGM1: Atip to Aring (1 mV)

EGM2: Can to RVcoil (1 mV)

A-A Interval (ms)

Markers

V-V Interval (ms)

5

6

Waveform suspended for 1 min 40 sec.
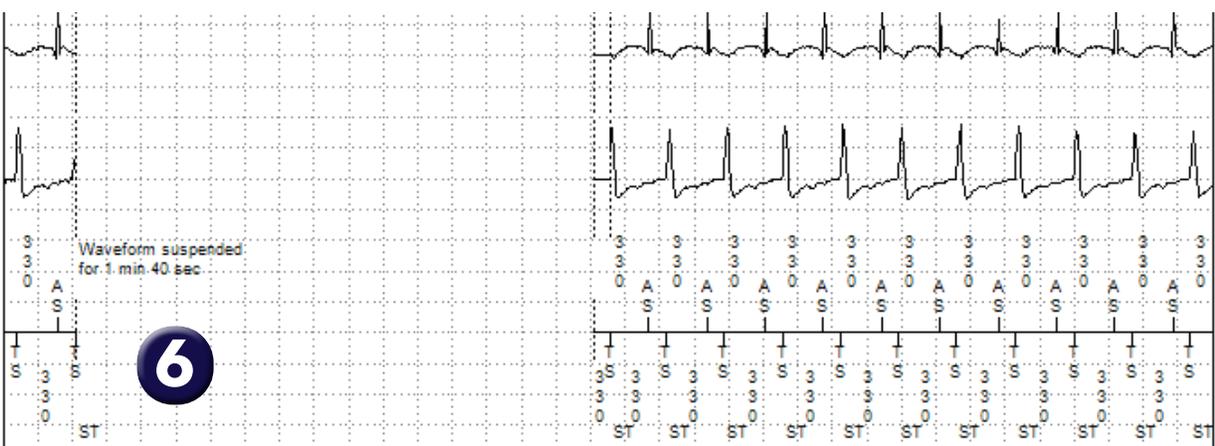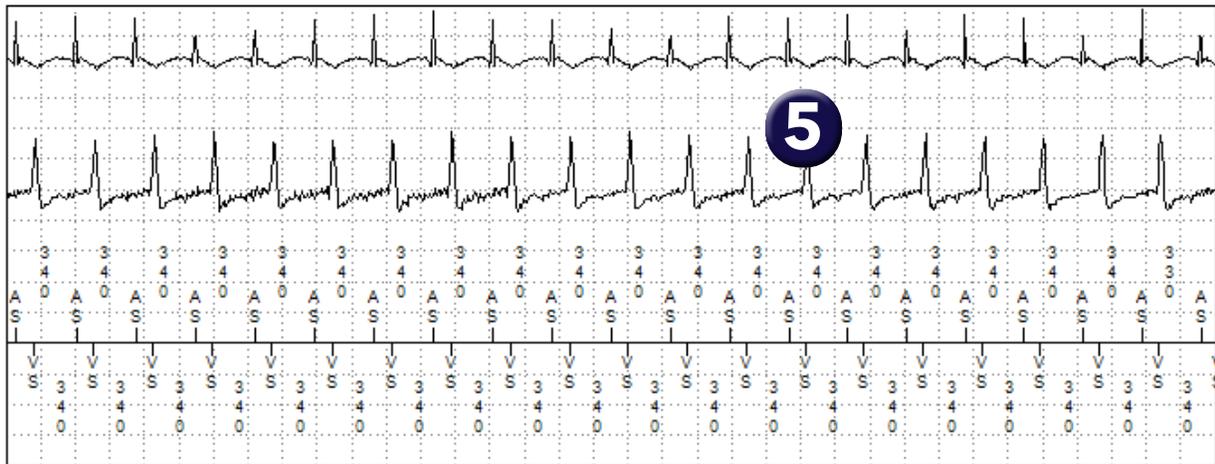
Episode Summary

Initial Type	SVT - Sinus Tach (spontaneous)
Duration	1.8 min
A/V Max Rate	194 bpm/194 bpm
V. Median	182 bpm (330 ms)
Activity at onset	Rest, Sensor = 55 bpm

Other Criteria Triggered

Sinus Tach

6

Wavelet Measurements Prior to Initial Withholding of Detection

Wavelet Result:	Wavelet not applied; withheld by other criteria
Template Status:	OK

-8.	Match	82 %
-7.	Match	79 %
-6.	Match	79 %
-5.	Match	82 %
-4.	Match	79 %
-3.	Match	79 %
-2.	Match	79 %
-1.	Match	79 %

7

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	330 ms (182 bpm)
FVT	via VF			270 ms (222 bpm)
VT	On	20	12	340 ms (176 bpm)
Monitor	Monitor	32		370 ms (162 bpm)

PR Logic/Wavelet

AF/Afl	On
Sinus Tach	On
Other 1:1 SVTs	Off
Wavelet	On, Match = 70%
Template	20-Jun-2016, Auto = Off
SVT V. Limit	270 ms

Other Enhancements

Stability	Off
Onset	Off
High Rate Timeout	
VF Zone Only	Off
All Zones	Off
TWave	On
RV Lead Noise	On+Timeout
Timeout	0.75 min

4

Polarity — RV

Pace Polarity	Bipolar
Sense Polarity	Bipolar

EGM	Source	Range	Sensitivity	
EGM1	Atip to Aring	+/- 8 mV	Atrial	0.3 mV
EGM2 (Wavelet)	Can to RVcoil	+/- 12 mV	RV	0.3 mV
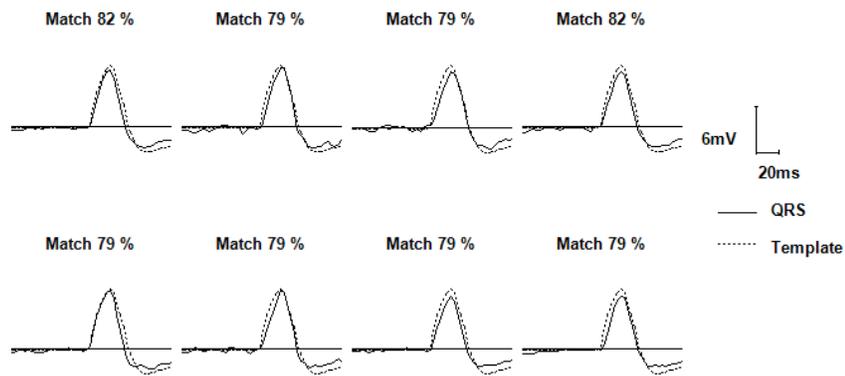
4 How many discrimination parameters are programmed?

The discrimination parameters (PR Logic and Wavelet) are programmed with a SVT V. Limit of 260 ms; the other SVT 1:1 criterion is set to 'Off'.

5 What is your diagnosis?

The diagnosis of sinus tachycardia seems likely, with a succession of AS-VS then AS-TS cycles.

6 What is the diagnosis made by the system?

As indicated on the trace, the device diagnoses sinus tachycardia (ST).

7 What are the results of Wavelet?

Wavelet supports the diagnosis of SVT, with all the QRS complexes analysed judged to be similar; Wavelet was not used because it was superseded by other criteria (PR Logic).

Key messages

- This young patient had experienced episodes of symptomatic VT requiring programming of a VT zone starting at 340 ms, increasing the risk of overlap with sinus rates during exercise.

- This episode had the characteristics of a sinus tachycardia (1:1 ratio between

the atria and ventricles, progressive acceleration and deceleration), well diagnosed by PR Logic.

- When the Sinus tach option is set to 'On', there are various stages involved in diagnosing sinus tachycardia.
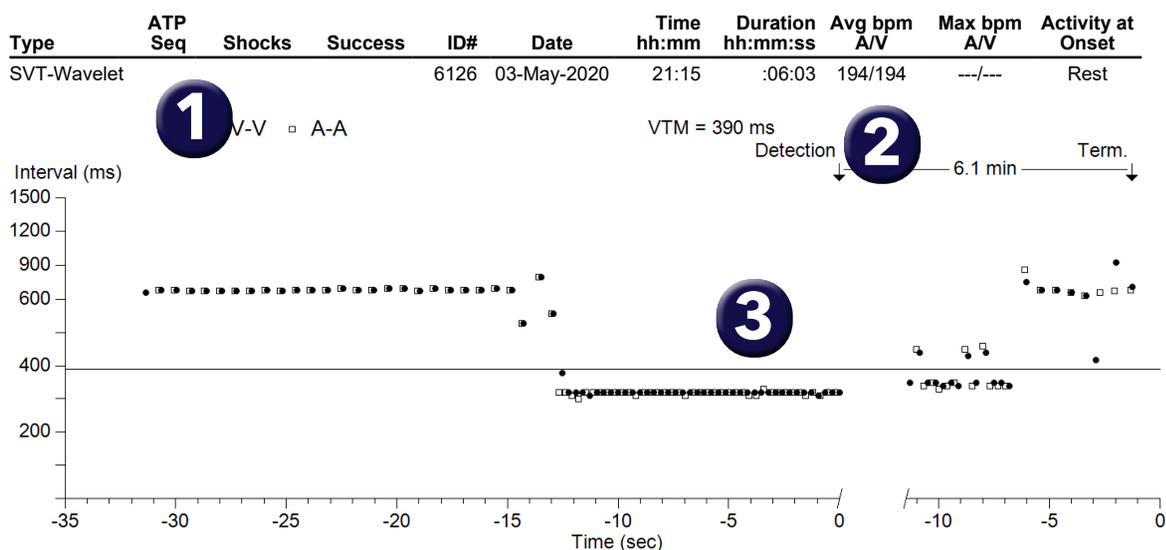
- The first step is to demonstrate that there is a 1:1 ratio between the atria and ventricles (check that there is no far-field R wave oversensing).

- The second step is to determine whether the RR intervals are compatible with a sinus tachycardia; for each ventricular interval, the device determines an adaptive range of expected RR intervals (based on an average value of the previous RR intervals); each RR interval is therefore defined as expected (within the range expected for a sinus tachycardia) or unexpected (outside the range expected for a sinus tachycardia).

- The third step is to determine whether PR intervals are compatible with a sinus tachycardia; for each interval, the device determines an adaptive range of expected PR intervals (based on an average value of the previous PR intervals); each PR interval is therefore defined as expected (within the range expected for a sinus tachycardia) or unexpected (outside the range expected for a sinus tachycardia).

- In the fourth step, the device establishes a sinus tachycardia counter based on the analysis of successive RR intervals and PR intervals.

- During a 1/1 tachycardia, if PR Logic concludes sinus tachycardia, Wavelet is not included in discrimination and therefore cannot modify the diagnosis; on the other hand, if PR Logic concludes VT with retrograde conduction, Wavelet is included in the discrimination; if the morphology of the ventricular complexes in tachycardia is considered different from the reference, the device confirms the VT diagnosis; on the other hand, if the morphology is considered similar, the device corrects the diagnosis and concludes supra-ventricular tachycardia.

15 — 1/1 tachycardia, PR Logic, Wavelet

Patient

Male implanted with a triple-chamber defibrillator (Amplia Quad CRTD) for ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
SVT-Wavelet				6126	03-May-2020	21:15	:06:03	194/194	---/---	Rest

1 — What was the diagnosis made by the defibrillator for this episode?

This episode has been classified SVT-Wavelet by the device.

2 — Which programmed zone appears on the graph?

A monitor zone is programmed from 390 ms.

3 — What diagnosis does the interval plot suggest?

The graph shows a 1/1 tachycardia with abrupt acceleration recorded in the monitor zone; spontaneous termination after about 6 minutes.

EGM1: Atip to Aring

(1 mV)

EGM2: Can to RVcoil

(1 mV)

A-A Interval (ms)

Markers

V-V Interval (ms)

Waveform suspended
for 5 min 50 sec
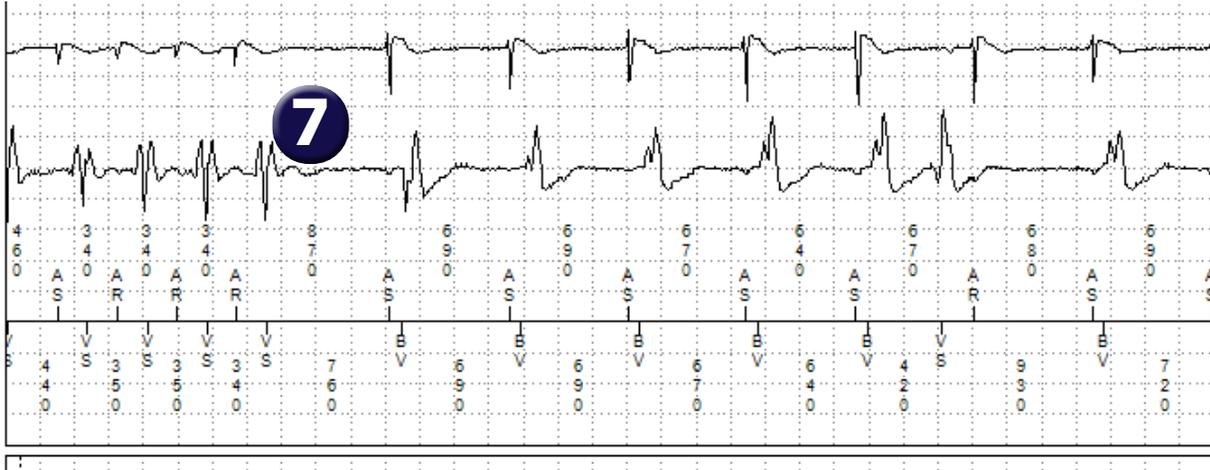
Episode Summary

Initial Type	SVT - Wavelet (spontaneous)
Duration	6.1 min
A/V Max Rate	---/---
V. Median	188 bpm (320 ms)
Activity at onset	Rest, Sensor = 60 bpm

Wavelet Measurements Prior to Initial Withholding of Detection

Wavelet Result:	SVT	
Template Status:	Inconsistent with intrinsic rhythm	
-8.	Match	76 %
-7.	No Match	64 %
-6.	Match	70 %
-5.	Match	70 %
-4.	Match	79 %
-3.	Match	70 %
-2.	Match	79 %
-1.	Match	76 %

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	310 ms (194 bpm)
FVT	Off			
VT	Off	40	12	
Monitor	Monitor	40		390 ms (154 bpm)

PR Logic/Wavelet

AF/Afl	On
Sinus Tach	On
Other 1:1 SVTs	On
Wavelet	On, Match = 70%
Template	14-Jun-2019, Auto = Off
SVT V. Limit	260 ms

Other Enhancements

Stability	Off
Onset	Off
High Rate Timeout	
VF Zone Only	Off
TWave	On
RV Lead Noise	On

Polarity   **RV**

Pace Polarity	Bipolar
Sense Polarity	Bipolar

EGM	Source	Range	Sensitivity	
EGM1	Atip to Aring	+/- 8 mV	Atrial	0.3 mV
EGM2 (Wavelet)	Can to RVcoil	+/- 12 mV	RV	0.3 mV

Match 76 %	No Match 64 %	Match 70 %	Match 70 %

6mV

20ms

——— QRS

········ Template

Match 79 %	Match 70 %	Match 79 %	Match 76 %
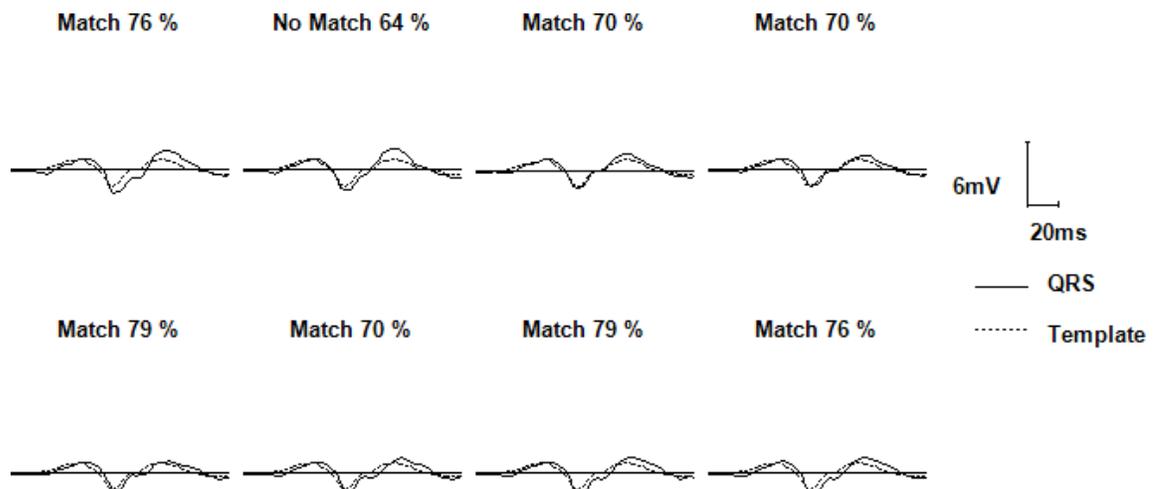
4 How many discrimination parameters are programmed?

The discrimination parameters (PR Logic and Wavelet) are programmed with a SVT V. Limit of 260 ms; the other SVT 1:1 criterion is programmed 'On'.

5 What information does the onset of arrhythmia give you?

The tachycardia starts with a rapid atrial rhythm, which is consistent with atrial tachycardia.

6 What are the possible diagnoses?

This is a 1/1 tachycardia; the possible diagnoses are therefore: atrial tachycardia with 1/1 conduction, junctional tachycardia, ventricular tachycardia with 1/1 retrograde conduction; the PR interval is relatively long with a VA interval shorter than the AV interval.

7 What information does the termination in arrhythmia give you?

The tachycardia stops spontaneously on a ventricular event, which is also in favour of atrial tachycardia.

8 What are the results of Wavelet?

Wavelet supports the diagnosis of SVT, with 7 of the 8 QRS complexes analysed similar to the reference template.

Key messages

- This patient presented with episodes of atrial tachycardia detected in the monitor zone; the tachycardias began with an atrial extrasystole and ended spontaneously with a ventricular complex; these elements support the diagnosis of atrial tachycardia but are not part of the defibrillator analysis.

- PR Logic gave a diagnosis of VT, but this was corrected by the Wavelet analysis.

- The device highlights a 1/1 tachycardia that is not compatible with sinus tachycardia (sudden acceleration of atrial and ventricular rates); PR Logic analyses the position and succession of P waves between 3 consecutive R waves to differentiate VT, atrial tachycardia and junctional tachycardia; in this example, the atrial activity does not occur just before or just after the ventricular activity (in favour of junctional tachycardia) but is located in the first half of the RR interval (in favour of VT with retrograde conduction rather than atrial tachycardia); PR Logic concludes that the diagnosis is VT.

- During a 1/1 tachycardia, if PR Logic concludes VT with retrograde conduction, Wavelet is integrated into the discrimination; if the morphology of the ventricular complexes in tachycardia is considered different from the reference, the device confirms the VT diagnosis; on the other hand, if the morphology is considered similar to the reference template, the device corrects the diagnosis and concludes supraventricular tachycardia; in this example, this avoids the delivery of inappropriate therapies.

16 PR Logic and conducted AF

Patient

Male implanted with a triple-chamber defibrillator (Cobalt Quad CRTD) for ischaemic cardiomyopathy.

Type	①	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
SVT-AF					4	20-Sep-2021	10:05	:16:31	429/167	545/182	Active
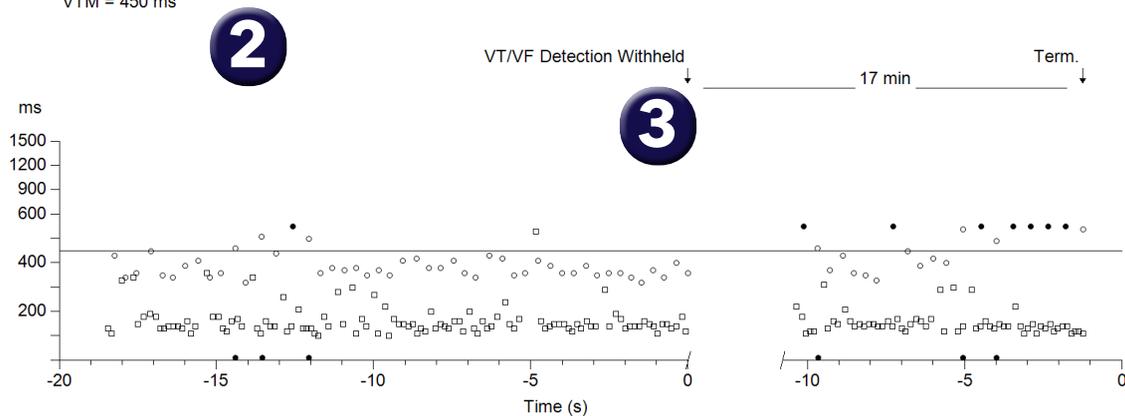
① What was the diagnosis made by the defibrillator for this episode?

This episode has been classified SVT-AF by the system.

② Which programmed zone appears on the graph?

A monitor zone is programmed from 450 ms.

③ What diagnosis does the interval plot suggest?

The graph shows a tachycardia detected in the monitor zone with atrial activity faster than ventricular activity and an irregular ventricular response; the graph is in favour of conducted AF.

EGM1: Atip to Aring

(1 mV)

EGM3: RVtip to RVring

(1 mV)

A-A (ms)

Markers

V-V (ms)

⑤

rm suspended
hin

Wavefo
for 16 m

245

Episode Summary

Initial Type	SVT - AF/Afl (spontaneous)
Duration	17 min
A/V Max Rate	545 bpm/182 bpm
V. Median	167 bpm (360 ms)
Activity at onset	Active, Sensor = 91 bpm

Device was in Mode Switch During Episode.

Wavelet Measurements Prior to Initial Withholding of Detection

Wavelet Result: Wavelet not applied; withheld by other criteria

-8.	Match	94 %
-7.	Match	91 %
-6.	Match	91 %
-5.	Match	91 %
-4.	Match	85 %
-3.	Match	91 %
-2.	Match	91 %
-1.	Match	88 %

6

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	320 ms (188 bpm)
FVT	via VF			280 ms (214 bpm)
VT	Off	24	12	
Monitor	Monitor	32		450 ms (133 bpm)

PR Logic/Wavelet

AF/Afl	On
Sinus Tach	On
Other 1:1 SVTs	On
Wavelet	On, Match = 70 %
Template	16-Sep-2021, Auto = On
SVT V. Limit	260 ms

Other Enhancements

Stability	Off
Onset	Off
High Rate Timeout	
VF Zone Only	Off
TWave	On
RV Lead Noise	On

4

4 How many discrimination parameters are programmed?

The discrimination parameters (PR Logic and Wavelet) are programmed with a SVT V. Limit of 260 ms.

Match 76 %   No Match 64 %   Match 70 %   Match 70 %

6mV

20ms

——— QRS

Match 79 %   Match 70 %   Match 79 %   Match 76 %

········ Template

5 What is your diagnosis?

The pattern is suggestive of conducted AF.

6 What are the results of Wavelet?

Wavelet supports the diagnosis of SVT, as the 8 QRS complexes analysed were considered similar to the reference template.

Key messages

- This patient presented with episodes of atrial fibrillation detected in the monitor zone and correctly classified by the defibrillator; this trace details the various stages leading to the diagnosis of AF by PR Logic.

- The device compares the atrial and ventricular rates; for a diagnosis of conducted AF, the median atrial interval must be less than or equal to 94% of the median ventricular interval; in this example, the atrial rate is clearly faster than the ventricular rate; this tracing corresponds to an episode with V<A.

- The device checks that there is no far-field R wave oversensing (oversensing of the R wave   on the atrial channel); PR Logic detects a far-field R wave if it detects both a succession of «short-long» sequences of A-A intervals (difference > 30 ms) and a short A-V interval (< 60 ms) or a short V-A interval (< 160 ms); to diagnose far-field R wave oversensing, the device must sense a far-field R wave
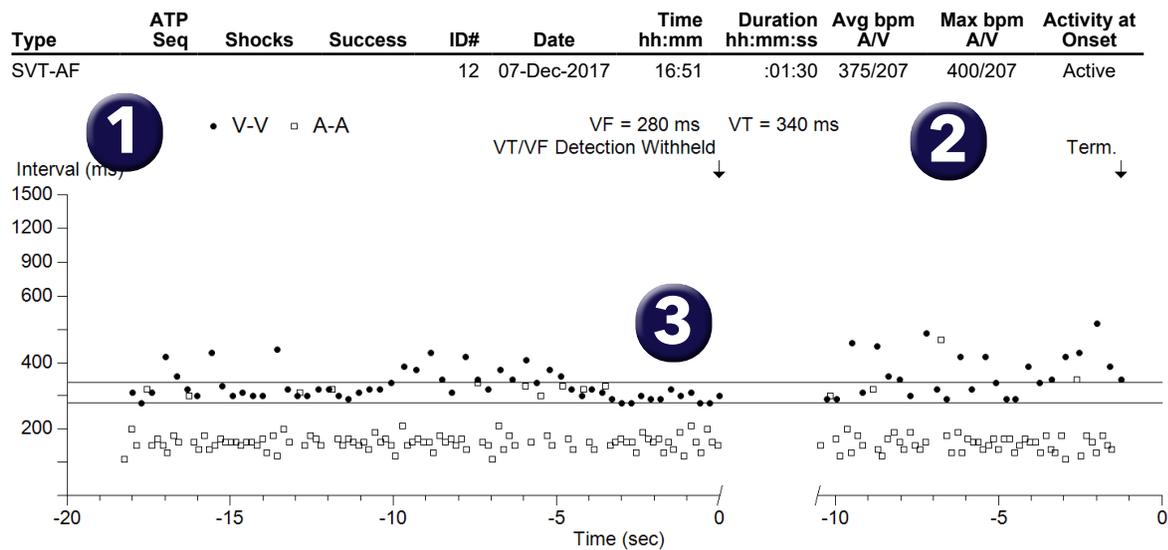
in at least 4 of the 12 most recent ventricular intervals; in this example, this type of sequence is not found, as the sensed atrial signals all correspond to atrial activity.

- The device analyses the atrial rhythm and assesses for the presence of atrial fibrillation; to do this, it counts the number of sensed atrial cycles between 2 sensed R waves (2 or more atrial signals between 2 ventricular signals => Counter +1, no atrial signals between 2 ventricular signals => Counter -1, 1 atrial signal between 2 ventricular signals => Counter +0 if different from the previous cycle); diagnosis compatible with AF if AF counter is greater than 6; in this example, the AF counter is well above 6 (in the majority of cycles, there are at least 2 atrial signals between 2 ventricular signals); at this stage, the 3 diagnoses to be differentiated are: bi-tachycardia (VT + AF), conducted AF, conducted atrial flutter.

- The device analyses the regularity of the ventricular rhythm using a different criterion to that used for a single-chamber defibrillator; the device counts the number of times the 2 most frequent ventricular intervals have occurred out of the last 18 ventricular intervals; if the sum of the 2 most frequent intervals represents more than 75% of the total cycles, the rhythm is considered to be regular; this is not the case in this example; the rhythm is irregular (the 2 most frequent cycles represent less than 50% of the total cycles); the device eliminates the diagnoses of bi-tachycardia and conducted flutter (regular ventricular rhythm) and retains the diagnosis of conducted AF.

- If PR Logic concludes conducted AF, Wavelet is not included in the discrimination and therefore cannot modify the diagnosis; on the other hand, if the PR Logic concludes double tachycardia (AF + VT), Wavelet is included in discrimination and can possibly correct the diagnosis.

17 conducted AF, PR Logic and Wavelet

Patient

Male implanted with a triple-chamber defibrillator (Cobalt Quad CRTD) for ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
SVT-AF				12	07-Dec-2017	16:51	:01:30	375/207	400/207	Active

1 What is the diagnosis made by the defibrillator?

This episode has been classified SVT-AF by the system.

2 Which programmed zone appears on the graph?

Two detection zones have been programmed with a VT zone of 340 to 280 ms.

3 What diagnosis does the interval plot suggest?

The graph shows a tachycardia detected in the VT zone with atrial activity faster than ventricular activity and an irregular ventricular response; the graph favours conducted AF.

EGM1: Atip to Aring

(1 mV)

5

EGM2: Can to RVcoil

(1 mV)

A-A Interval (ms):

Markers

V-V Interval (ms):

6

Waveform for 1 min.

AF

suspended
0 sec

Episode Summary

Initial Type	SVT - AF/Afl (spontaneous)
Duration	1.5 min
A/V Max Rate	400 bpm/207 bpm
V. Median	207 bpm (290 ms)
Activity at onset	Active, Sensor = 94 bpm

Other Criteria Triggered

AFib/AFlutter

Wavelet Measurements Prior to Initial Withholding of Detection

Wavelet Result:	Wavelet not applied; withheld by other criteria
Template Status:	OK

-8.	No Match	55 %
-7.	No Match	64 %
-6.	No Match	37 %
-5.	No Match	43 %
-4.	Match	70 %
-3.	No Match	52 %
-2.	Match	70 %
-1.	No Match	49 %

⑦

Parameter Settings

		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	280 ms (214 bpm)
FVT	Off			
VT	On	16	12	340 ms (176 bpm)
Monitor	Monitor	32		370 ms (162 bpm)

PR Logic/Wavelet

AF/Afl	On
Sinus Tach	On
Other 1:1 SVTs	On
Wavelet	On, Match = 70%
Template	19-Sep-2017, Auto = Off
SVT V. Limit	260 ms

Other Enhancements

Stability	Off
Onset	Off
High Rate Timeout	
VF Zone Only	Off
All Zones	Off
TWave	On
RV Lead Noise	On+Timeout
Timeout	0.75 min

④

Polarity — **RV**

Pace Polarity	Bipolar
Sense Polarity	Bipolar

EGM	Source	Range	Sensitivity	
EGM1	Atip to Aring	+/- 8 mV	Atrial	0.3 mV
EGM2 (Wavelet)	Can to RVcoil	+/- 12 mV	RV	0.3 mV

No Match 55 %   No Match 64 %   No Match 37 %   No Match 43 %

6mV

20ms

—— QRS

········ Template

Match 70 %   No Match 52 %   Match 70 %   No Match 49 %

4 How many discrimination parameters are pro-grammed?

The discrimination parameters (PR Logic and Wavelet) are programmed with a SVT V. Limit of 260 ms.

5 How does the VT counter work?

Some cycles fall within the VT zone, others do not; cycles classified as VS systematically reset the VT counter to 0.

6 What is the diagnosis made by the defibrilla-tor?

The tachycardia accelerates and stabilises in the VT zone; after 16 consecutive cycles classified as VT, the VT counter is full; PR Logic classifies the episode as AF.

7 What are the results of Wavelet?

Wavelet is not used because it is superseded by PR Logic; if used, it would have led to the diagnosis of VT because only 2 ventricular complexes are classified as similar to the reference.

Key messages

- This patient presented with multiple episodes of AF correctly discriminated by PR Logic; this tracing allows us to discuss the conditions for Wavelet intervention.

- The sequence used by PR Logic to diagnose AF is identical to the previous tracing: 1) the atrial rhythm is faster than the ventricular rhythm (V<A); 2) the sensed atrial signals correspond to atrial activation (no far-field R wave oversensing); 3) the AF counter is greater than 6; 4) the ventricular rhythm is irregular.

- When PR Logic and Wavelet are programmed simultaneously and PR Logic concludes SVT-AF, the Wavelet results cannot change the diagnosis, which is desirable in this example since the Wavelet data favoured the diagnosis of VT.
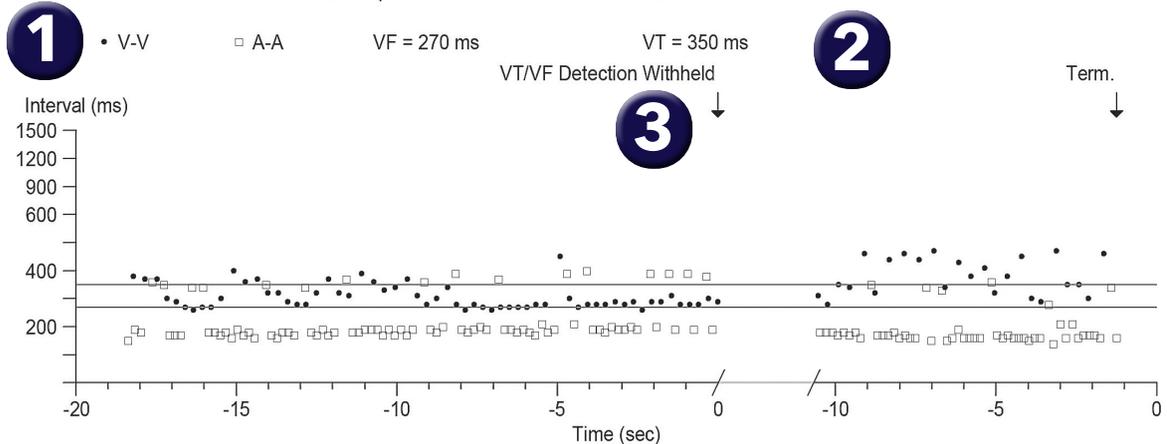
18 AF with regular ventricular response, PR Logic and Wavelet

Patient

Male implanted with a dual-chamber defibrillator (Evera XT DR) for ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
SVT-Wavelet				57	21-Sep-2015	11:52	:50	214/214	375/---	Active

1 What is the diagnosis made by the defibrillator for this episode?

This episode has been rated SVT-Wavelet by the device.
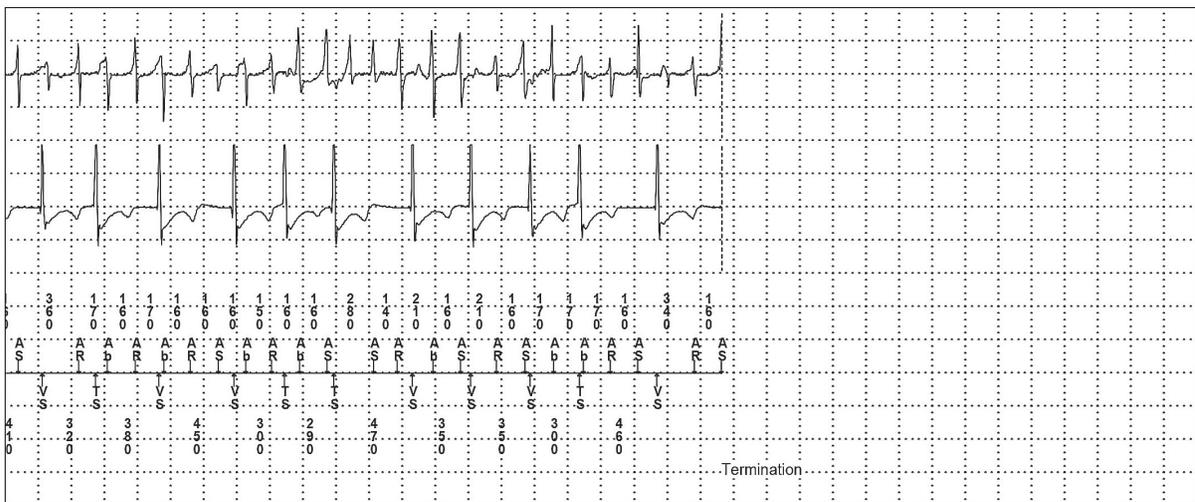
2 How many detection zones are programmed?

Two detection zones have been programmed with a VT zone of 350 to 270 ms.

3 Quel diagnostic vous suggère le graphe ?

The graph shows a tachycardia detected in the VT zone with atrial activity faster than ventricular activity and an irregular ventricular response which regularises in a second phase; the graph is in favour of conducted AF.

EGM1: Atip to Aring
(1 mV)

EGM3: RVtip to RVring
(1 mV)

A-A (ms):

Markers.

V-V (ms):

Panel 1 markers:

A-A (ms)	150	190	180	360	350	170	170	170	340	340	180	180	170	180	190	170	180	360	170	160	180
Markers	AR	Ab	AR		AR	AR	Ab	AR		Ab	AR	Ab	AR	AR	AR	Ab	AR	Ab	AR	AR	Ab
V-V (ms)		380	370	370	300	290	270	260	270	270	300	400	360	370	320	320	290				

⑤

Panel 2 markers (partial):
180 170 340 180 170 190 170 180 370 180 190 190 170 190 170 190 190 190 360 190 180 200 390 190 190 200 370 190 190 180

⑥

Waveform suspended for 40 sec

WV

Termination

Episode Summary

Initial Type	SVT - Wavelet (spontaneous)
Duration	50 sec
A/V Max Rate	375 bpm/---
V. Median	207 bpm (290 ms)
Activity at onset	Active, Sensor = 76 bpm

Device was in Mode Switch During Episode.

Other Criteria Triggered

Wavelet

Wavelet Measurements Prior to Initial Withholding of Detection

Wavelet Result:	SVT	
Template Status:	OK	
-8.	No Match	67 %
-7.	Match	82 %
-6.	Match	82 %
-5.	Match	88 %
-4.	Match	73 %
-3.	Chatch	76 %
-2.	Match	73 %
-1.	Match	88 %

7

Valeurs paramètres		Initial	Redétect	Intervalle V. (fréq.)
FV	Marche	24/32	12/16	270 ms (222 min-¹)
TVR	Arrêt			
TV	Marche	16	12	350 ms (171 min-¹)
Moniteur	Arrêt	28		

PR Logic/MorphoLog		Autres discriminations	
FA/flA	Marche	Stabilité	Arrêt
Tach sinus	Marche	Démarrage brutal	Arrêt
Autres TSV 1:1	Arrêt	Durée max. TSV	
MorphoLog	Marche, Similitude =70 %	Zone FV uniquement	Arrêt
Morph. réf.	25-Mar-2014, Auto =Marche	Toutes les zones	Arrêt
Limite V. TSV	270 ms	Onde T	Marche
		Bruit de sonde VD	Marche+Durée max.
		Durée max.	0.75 min

4 How many discrimination parameters are programmed?

The discrimination parameters (PR Logic and Wavelet) are programmed with a SVT V. Limit of 270 ms.

5 How does the VT counter work?

Some cycles correspond to the VT zone, others do not; cycles classified as VS systematically reset the VT counter to 0.

6 What is the diagnosis made by the defibrillator?

The tachycardia accelerates and becomes regular in the VT zone; after 16 consecutive cycles classified as VT, the VT counter is filled; the PR Logic classifies the episode as VT; Wavelet corrects the diagnosis and leads to a diagnosis of SVT.

7 What are the results of Wavelet?

Wavelet is used because PR Logic has concluded VT; Wavelet leads to the diagnosis of SVT because 7 out of 8 ventricular complexes are classified as similar to the reference template.
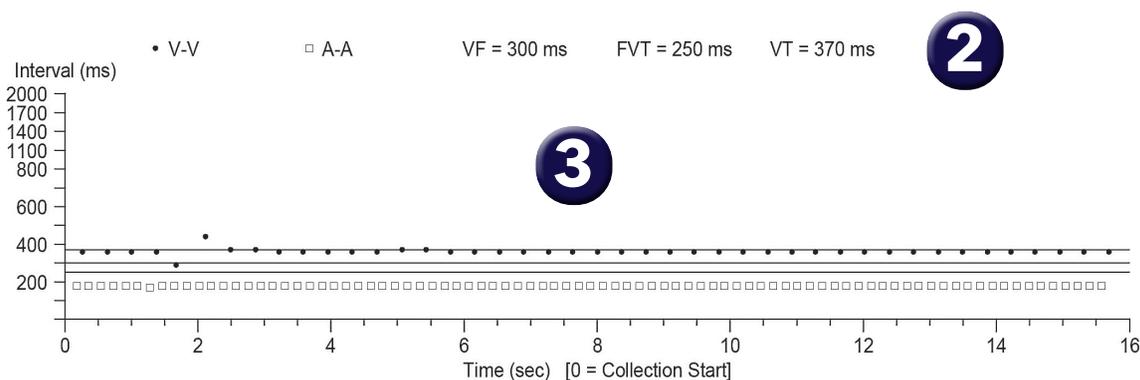
Key messages

- This tracing highlights the different stages of discrimination during an episode of conducted AF; the joint programming of PR Logic and Wavelet considerably reduces the risk of inappropriate therapies in this context.

- For the device to be fooled into delivering inappropriate therapy during conducted AF, the tachycardia must first stabilise for a sufficient duration in the VT zone without any long cycles that would reset the VT counter; the recommendation to increase the number of cycles required (at least 30 in the VT zone) significantly reduces the risk of inappropriate therapy in this setting (30 consecutive cycles in the VT zone without any long cycles).

- Secondly, if the VT counter is full, PR Logic intervenes; if the ventricular rhythm is irregular, PR Logic concludes that there is conducted AF; in this example, the various stages of analysis by the PR Logic reveal 1) an atrial rate higher than the ventricular rate, 2) no far-field R wave oversensing, 3) an AF counter > 6, 4) a rhythm judged to be stable over the last 18 cycles with a preponderance of cycles measured at 280 or 290 ms (the 2 most frequent); PR Logic therefore incorrectly concludes that there is bi-tachycardia.

- For a tachycardia with an atrial rate greater than or equal to the ventricular rate, when PR Logic suspects VT, morphology analysis can correct a diagnostic error; in this example, we can see that 7 of the 8 QRS complexes analysed have a value greater than the programmed threshold of 70%, which is in favour of conducted AF; the final diagnosis is therefore SVT and no therapy is delivered.

19 | PR Logic and atrial flutter

Patient

Male implanted with a dual-chamber defibrillator (InSync Sentry) for ischaemic cardiomyopathy.

ID#	Date/Time	A. Cycle	V. Cycle	Duration	Reason
66	Jun 19 19:03:25	180 ms	360 ms	49 sec	AFib/AFlutter

1

• V-V   □ A-A   VF = 300 ms   FVT = 250 ms   VT = 370 ms   **2**

Interval (ms)

3

2000
1700
1400
1100
800

600

400

200

0   2   4   6   8   10   12   14   16

Time (sec)   [0 = Collection Start]

1 What was the diagnosis made by the defibrillator for this episode?

This episode has been classified AFib/AFlutter by the system.

2 How many detection zones are programmed?

Three detection zones have been programmed with a VT zone of 370 to 300 ms.

3 What diagnosis does the interval plot suggest?

The graph shows a regular tachycardia in the atrium and a regular tachycardia in the ventricle.

EGM1: Atip to Aring
(1 mV)

EGM2: RVtip to RVring
(1 mV)

A-A Interval (ms)

Marker Annotation

V-V Interval (ms)

5

AF   AF   AF   AF

AF   AF   AF   AF   AF   AF   AF   AF   AF

Episode Summary

A. Median Cycle   180 ms
V. Median Cycle   360 ms
V. Average Cycle   360 ms
SVT Duration   49 sec

Device was in Mode Switch during SVT/NST episode.

SVT Criteria Triggered

AFib/AFlutter

Parameter Settings

	Enable	Initial	Redetect	V Interval (Rate)
VF	On	12/16	9/12	300 ms (200 bpm)
FVT	via VF			250 ms (240 bpm)
VT	On	16	12	370 ms (162 bpm)

PR Logic
AFib/AFlutter   On
Sinus Tach   On
Other 1:1 SVTs   On
SVT Limit   300 ms

4

Other Enhancements
Stability   40 ms

Additional Settings
1:1 VT-ST Boundary   50 %
High Rate Timeout   Off

Sensitivity
Atrial   0.3 mV
Ventricular   0.3 mV

	EGM 1	EGM 2
EGM Source	Atip to Aring	RVtip to RVring
EGM Range	+/- 8 mV	+/- 8 mV

4 How many discrimination parameters are programmed?

The discrimination parameters (PR Logic and Stability) are programmed with a SVT V. Limit of 300 ms.

5 What is the most likely diagnosis?

The most likely diagnosis is atrial flutter with 2/1 conduction.

6 What is the diagnosis made by the defibrillator?

The device diagnoses AF/AFlutter and inhibits therapies.

Key messages

- This patient presented with episodes of atrial flutter with 2/1 conduction; this tracing details the various stages leading to the diagnosis of atrial flutter by PR Logic.

- Is the ventricular rate faster than the atrial rate? If so, PR Logic diagnoses VT without further analysis; if, as in this example, the atrial rate is faster than the ventricular rate, the analysis will continue.

- Is there far-field R wave oversensing that could cause an error in the analysis of the atrial rate? PR Logic concludes that the far-field R wave has been oversensed by the atrial channel if it detects a succession of short- long atrial cycles and either a short PR interval (<60 ms) or a short RP interval (< 160 ms); in this example, we do not find this type of sequence, as the PP intervals are perfectly regular (180 ms).

- Is the atrial rate compatible with an atrial arrhythmia? An AF counter analyses the number of atrial signals detected between 2 ventricular complexes; when the device detects at least 2 atrial events between 2 R waves, the counter is incremented (+1); when the device does not detect an atrial event between 2 R waves, the counter is decremented (-1); when the device detects an atrial event between 2 R waves, the counter is decremented (-1) if the previous cycle was identical (one atrial event between 2 R waves); the counter is not modified if the previous cycle was different; the diagnosis of AF is possible if this counter (once any far-field R wave oversensing has been corrected) is at least +6; in this example, the AF counter increases with each cycle and is therefore well above +6; the 3 possible diagnoses at this stage are: conducted AF, conducted flutter and double tachycardia (AF/flutter + VT).

- Is the ventricular rhythm irregular and therefore in favour of conducted AF? The analysis of ventricular stability differs from the way stability is assessed with a single-chamber defibrillator; the device analyses the RR intervals over 18 consecutive cycles (only cycles longer than 240 ms are analysed) and deter-

mines the percentage of cycles observed for a given interval (…360ms, 350 ms, 340 ms, 330 ms, 320 ms, 310 ms, 300 ms …).); the device sums the percentages of the 2 most frequently encountered intervals; if the sum of the 2 percentages is greater than 75%, the rhythm is considered to be regular; if, on the other hand, the sum is less than 50% (high cycle variability), the rhythm is considered to be irregular and in favour of conducted AF; in this example, the rhythm is perfectly stable (360 ms) which means that the diagnosis of conducted AF can be ruled out; the 2 possible diagnoses at this stage are therefore : conducted atrial flutter and double tachycardia (AF/flutter + VT).

- Is there atrio-ventricular association (conducted flutter) or atrio-ventricular dissociation (double tachycardia)? Atrio-ventricular dissociation is diagnosed if for at least 4 of the last 8 RR intervals there is either no atrial event or there is a difference of more than 40 ms between the PR interval analysed and the average of the previous 8 PR intervals; in this example, the PR intervals are perfectly fixed, which explains why the device arrives at the final diagnosis of conducted atrial flutter and therapies are not delivered.

- If PR Logic concludes atrial flutter, Wavelet is not included in discrimination and therefore cannot modify the diagnosis; on the other hand, if the PR Logic concludes double tachycardia, Wavelet is included in discrimination.

20 double-chamber discrimination and bi-tachycardia

Patient

Male implanted with a dual-chamber defibrillator (Evera XT DR) for ischaemic cardiomyopathy.

Type	ATP Seq	Shocks	Success	ID#	Date	Time hh:mm	Duration hh:mm:ss	Avg bpm A/V	Max bpm A/V	Activity at Onset
VT	1		Yes	10659	21-Feb-2022	17:01	:24	240/194	240/194	Active
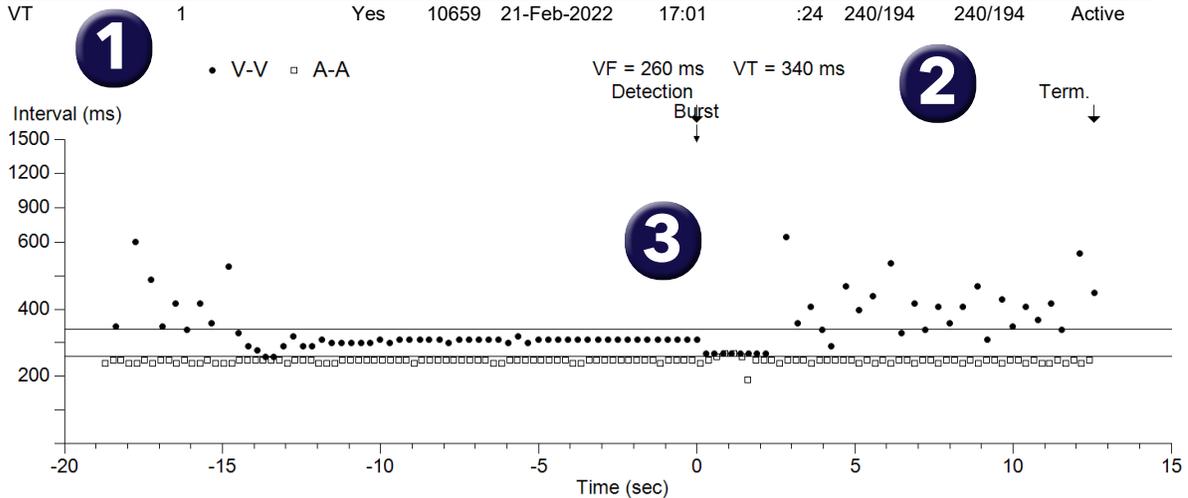
① What was the diagnosis made by the defibrillator for this episode?

This episode was rated VT + SVT by the device.

② How many detection zones are programmed?

Two detection zones have been programmed with a VT zone of 340 to 260 ms.

③ What diagnosis does the interval plot suggest?

The graph shows a regular tachycardia in the atrium, an initially irregular ventricular rhythm (compatible with conducted AF) which accelerates and becomes regular (compatible with VT); a burst re-establishes the initial irregular ventricular rhythm.

Episode Summary

Initial Type	VT (+SVT) (spontaneous)
Duration	24 sec
A/V Max Rate	240 bpm/194 bpm
V. Median	194 bpm (310 ms)
V. Stability	0 ms - 0 ms
Activity at onset	Active, Sensor = 61 bpm
Last Therapy	VT Rx1: Burst, Successful

Initial VT/VF Detection Withheld By

None

(7)

Therapies	Delivered	Charge	Ohms	Energy
VT Rx 1 Burst	Seq 1			
|				
Termination				

Wavelet Measurements Prior to Initial VT/VF Detection

Wavelet Result:	VT/VF	
Template Status:	OK	
-8.	No Match	34 %
-7.	No Match	25 %
-6.	No Match	37 %
-5.	No Match	40 %
-4.	No Match	28 %
-3.	No Match	31 %
-2.	No Match	37 %
-1.	No Match	34 %
0.	Detection	

(8)

Onset Criterion Result

Sudden Onset - VT.

Parameter Settings		Initial	Redetect	V. Interval (Rate)
VF	On	30/40	12/16	260 ms (231 bpm)
FVT	Off			
VT	On	48	12	340 ms (176 bpm)
Monitor	Off	32		

(4)

PR Logic/Wavelet

AF/Afl	On
Sinus Tach	On
Other 1:1 SVTs	Off
Wavelet	On, Match = 70%
Template	07-Jul-2015, Auto = On

Other Enhancements

Stability	Off
Onset	Monitor (81%)
High Rate Timeout	
VF Zone Only	Off
All Zones	Off
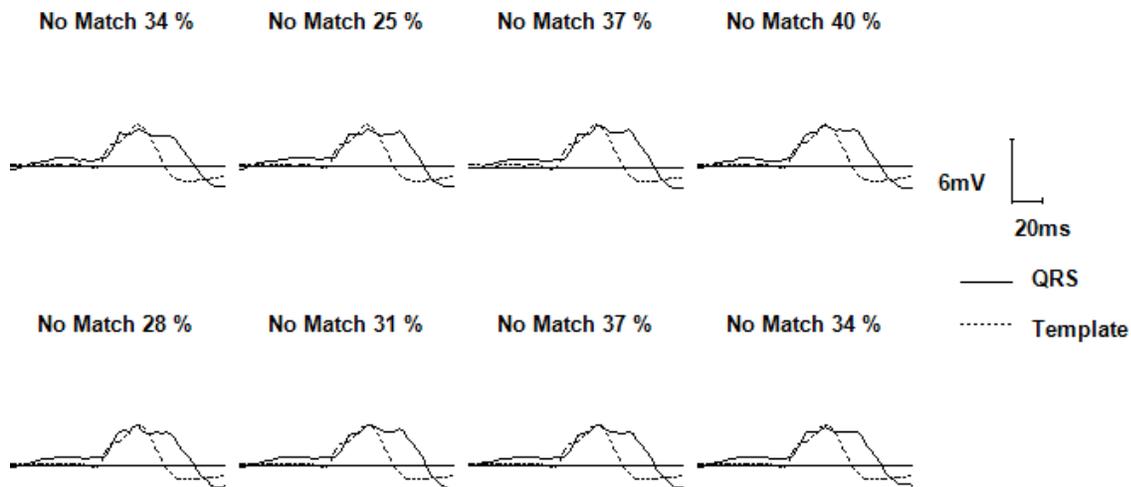
No Match 34 %   No Match 25 %   No Match 37 %   No Match 40 %

6mV

20ms

——— QRS

No Match 28 %   No Match 31 %   No Match 37 %   No Match 34 %

········· Template

4 How many discrimination parameters are programmed?

The discrimination parameters (PR Logic and Wavelet) are programmed with a SVT V. Limit of 260 ms.

5 What is the most likely diagnosis at the start of the trace?

The trace is compatible with conducted AF.

6 What is the most likely diagnosis for the rest of the trace?

The ventricular rhythm accelerates and becomes more regular, with a clear change in the morphology of the ventricular complexes compared with the beginning of the trace.

7 What is the diagnosis made by the system?

Implementation of PR Logic and Wavelet results in a diagnosis of VT; a burst is delivered with termination of VT.

8 What are the results of Wavelet?

Wavelet is used because PR Logic has concluded VT; Wavelet leads to the diagnosis of VT because the 8 ventricular complexes are classified as different from the reference template.

Key messages

- This patient presented with episodes of bi-tachycardia with VT + AF.

- PR Logic diagnoses bi-tachycardia in several steps: 1) the atrial rhythm is faster than the ventricular rhythm; 2) there is no far-field R wave oversensing; 3) the atrial rhythm is compatible with AF (AF counter > 6); 4) the ventricular rhythm is regular (300 ms and 310 ms represent more than 75% of the last 18 ventricular cycles before diagnosis); 2 possible diagnoses: bi-tachycardia and conducted atrial flutter; 5) there is no atrioventricular association leading to the diagnosis of bi-tachycardia and excluding conducted atrial flutter.

- When PR Logic diagnoses bi-tachycardia (VT + SVT), Wavelet is interrogated: in this example, the change in morphology is obvious, the 8 complexes are different from the stored template and Wavelet confirms the diagnosis of VT.